

THE INFLUENCE OF SILICON FERTILIZATION ON THE DEVELOPMENT AND
CONTROL OF BLAST CAUSED BY *Magnaporthe oryzae* (Rhizoct) Wurt
IN UPLAND RICE

By

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Abstract of Dissertation Presented to the Graduate School
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THE INFLUENCE OF SILICON FERTILIZATION ON THE DEVELOPMENT AND
CONTROL OF BLAST CAUSED BY *Magnaporthe oryzae* (Helen) Bar
IN UPLAND RICE

By

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Experiments were conducted from 1954-1956 to determine if rice blast could be managed with silicon alone or with fungicides applied at strategic times or reduced rates. In 1954, rice at two locations in Colombia was treated with 400 kg. of silicon (Si)/ha² alone or with fungicides applied at different growth stages of rice. Leaf blight was reduced 63-75% at both locations by Si and Si plus silicophanes, as compared to the control. Silicophanes and surface applications of fungicide generally decreased neck blight and grain discoloration. Single applications of fungicide averaged yields 43-47%. At one location, neck blight was reduced and yield was increased by Si alone, and leaf blight was reduced 30-52% by Si alone or with fungicides.

In 1955 and 1956, Si was applied at 1000 kg./ha², in combination with silicophanes and fungicides at reduced rates to determine effects on blight and yield. At two locations,

severity of blight and final damage for *S. glabra* and *S. glauca* infestations were 33-75% lower than the untreated checks. Final damage and overall severity of blight for *S. glabra* were not different from plots treated with full rates of benlatephos in 1955. Loss were reduced 18-42% in 1956. In general, *S. glabra* increased yields as well as full rates of fungicide. Silicates applied in 1955 had residual activity against blight in 1956.

Resistant, partially resistant, and susceptible cultivars were fertilized with *S. glauca* extracts effective on blight, leaf mold, and pod rot. Leaf blight was controlled as effectively by *S. glauca* partially resistant and susceptible cultivars as on resistant cultivars without *S. glauca*. Leaf mold was generally reduced on all cultivars by *S. glauca*. Pod rot was reduced by *S. glauca* on partially resistant and susceptible cultivars. Yields were greater on *S. glauca* treated cultivars than untreated cultivars.

Silicates affected several components of resistance to blight in susceptible, partially resistant, and resistant cultivars. The number of sporulating lesions was reduced by silicates. Lesion size and sporulating lesions was reduced by *S. glauca*.

Silicates can be used to manage rice diseases, and may be useful to increase rice yields without further genetic improvements.

CHAPTER I INTRODUCTION

More than 60% of the world's population relies on rice (*Oryza sativa* L.) as a major source of carbohydrates (2%). Rice is cultivated mainly in irrigated, lowland ecosystems and in upland, wet-dry, ecosystems (18,21). Rice grown in flooded ecosystems accounts for 50% of worldwide production, and upland rice provides the remaining 50% (30).

Water, a major constituent of the earth's crust and the second most abundant element in agricultural systems, is critical among factors typically considered to be necessary for plant growth. Despite this, water-use accounts for up to 10% of total biomass for certain plant species (37,38). Plants, including rice, that have access to suitable water often exhibit improved growth, disease resistance, resistance to insect feeding, improved mineral nutrients, and reduced mineral toxicity (47,36,137).

Upland rice is currently grown on approximately 30 million hectares of potentially water-deficient soils worldwide (23,24). The growing systems of Latin America, composed of Upland and Genetic, covers approximately 300 million hectares, and portions are under development for pasture and cropping (11). In Colombia, rice production is being introduced into the northeast to meet expanding demands and also as a cost-effective means of establishing productive pasture lands (11), however, rice cultivation is limited by soil acidity and, more importantly, disease. In fact, the major limiting factor to rice farmers in upland systems is that, caused by *Helminthosporium* grisea (Patent) Barr (15,16). Other diseases vary from season to season in their significance,

earliest/mid earliest leaves spot, caused by *Chloroidea nebulosum* (Br.-R. Kufingradu in the French), the latest/mid leaf spot caused by *Microsporiella allonensis* Thum., sheath blight, caused by *Phoma sp.* *occum*-*sp.* (Br.-R. Kufingradu), and grain discolours, caused by a complex of events and fungi (25-31,345).

Application of fungicides and the utilization of resistant rice cultivars are the management tools now used for blast and other diseases (32,34,36, 113). Because of their high cost, fungicides are of questionable value to poor farmers in upland ecosystems (35). The use of resistant cultivars has limitations, as the genetic variability of rice pathogens, such as *M. grisea*, results in the breakdown of resistance within a few years after release of the cultivar (3,34,36). Other options need to be investigated to control diseases of rice, and the role of silicon fertilization is one possibility. In previous research, Dattol et al. (4,44), Akelah (4), and Caron Veronesi et al. (37) demonstrated that application of silicon to silicon-fertilized soils resulted in increased yields and reduced severity of disease. Silicon treatments also have been shown to control blast at levels comparable to commercially available fungicides (48). Therefore, further research is necessary to determine the various components of the role of silicon in reducing diseases of rice.

The present study was initiated to evaluate the performance of cultivars with fungicides applied at different spray schedules and reduced rates for the control of leaf blast and leaf sheath, and to improve grain yield and quality. Further studies were conducted to determine which silicon sources with cultivars of rice with various levels of resistance to blast on the control of leaf disease. Finally, to understand how silicon acts to reduce blast on rice, the effects of silicon on several components of resistance to blast

were studied. Information obtained from these studies will be useful to determine whether the incorporation of tobacco use cessation and management strategies would provide an effective means to reduce impacts of costly lung cancer and fatalities, to complement measures to limit its use and plant, and to provide greater insight into the mechanisms by which tobacco acts to reduce blood and other diseases of man.

CHAPTER I REVIEW OF LITERATURE

Rice and diet globalization Rice (*Oryza sativa* L.) is the major source of calories for roughly 80% of the world's population (95). *Oryza sativa*, along with *O. glaberrima* represents the main species of cultivated rice that have been associated with man for over 5,000 years (15). Rice is thought to be the product of origin of *O. sativa*, and records of its cultivation date back to 3,000 BC (64-111). Two major races of *O. sativa*, Indica and Japonica, are the types planted in greatest abundance. Indica types are characterized by tall plants that produce large grains and are thought to have evolved in tropical areas. Japonica types, which are typically short, stunted plants that produce small grains, likely originated in temperate areas (64,111).

The ability of rice as a food crop system is part to its adaptability to diverse climates, soil types, and water regimes. When rice is grown in areas defined as tropical lowlands, however, it is also cultivated as far north as latitude 32° and as far south as latitude 12° at altitudes that range from sea level to 3,000 m (64,111). Rice production is categorized by the type of ecosystem in which it is grown. Five major rice ecosystems were originally studied: lowland, upland, and flood plains (95). The International Rice Research Institute (IRRI) defines an irrigated rice ecosystem as one in which rice is grown in flooded (paddies) fields with a controlled source of irrigation that uses no more crops annually (95). In the studied lowland ecosystem, rice is grown in flooded fields but differs from the irrigated system as that irrigation water is provided solely by rainfall.

The depth of irrigation water raised cannot exceed 50 cm for more than 10 days continuously (33). Upland rice ecosystems vary in land type from latitudes to latitudes, and are characterized by dry cultivation, direct seeding, and irrigation via natural rainfall. No appreciable accumulation of surface water occurs in upland fields (34,35). Flood-prone ecosystems are those in which the rice crop may be temporarily submerged (1-10 days) or subjected to standing water of interest 30 and 400 cm from 1-2 months. The ecosystem type includes deepwater and floating rice (33-36). In terms of global rice production, irrigated ecosystems account for 47% of global production, wetland lowland ecosystems produce 38%, upland ecosystems are responsible for 10%, and flood-prone ecosystems provide the remaining 15%. The International Rice Research Institute estimates that there are approximately 84, 56, 18, and 11 million hectares planted in irrigated, wetland lowland, upland, and flood-prone rice, respectively (33). Of the 18 million hectares of upland rice cultivated worldwide, nearly 1.7 million are located in the countries of Latin America.

Rice in the United States is grown on approximately 21 million hectares in flooded, irrigated fields (36). Arkansas, Mississippi, Missouri, and Northern Louisiana accounted for 59.7% of the rice produced in the U.S. in 1991. Southern Louisiana and Texas produced 17%, and California produced 11.7% of the total (36). In Florida, the first rice planted to rice in 1951 totaled 1,488 hectares and the value of the rice crop was about \$10 million (33).

The rice plant: *Oryza sativa* is a semperannual grass belonging to the family Poaceae (37). Characteristics of *O. sativa* include a diploid genome with 24 chromosomes, cylindrical, hollow culms that are jointed, flat, alternately borne leaves

that consist of a stem-enveloping sheath and a lamina, a fibrous root system, and terminal inflorescences, called panicles. Root are strong branched and hair-like roots.(13,14,15)

Rice has several anatomical and physiological mechanisms that permit its colonization in aquatic systems. Because the flooded soil at the root-soil interface contains little O_2 , respiration of roots brings about a rapid depletion of the element (16, 17)

Since O_2 is necessary as an electron acceptor in the electron transport chain of aerobic respiration, a lack of O_2 results in cell death, and thus death of the root and plant (18)

Rice possesses adaptations for survival in anoxic/aerophilic or anoxic/aerobic environments

Colonization in an anoxic environment results in the emergence of the aerenchyma root followed by the coleoptile, however, if the seed germinates in an anoxic environment, the coleoptile emerges first. The root develops only after the coleoptile reaches ventral portions of the environment (19). The roots of rice plants form aerenchyma within 48 h after germination (20). There are connected to internal air spaces in the culm, which are in turn connected to another space in the leaf sheath and leaf. This provides a pathway for the diffusion of air from the culm to the actively dividing root tips. Roots of rice are rarely found below depths of 40 cm due to the limited ability of the aerenchyma to deliver oxygen to the root tips (15, 17, 24). They also are capable of utilizing respiratory pathways that consume internal molecular oxygen, and also can undergo fermentative cycles that permit growth in low oxygen situations. Rice roots also have been reported to exploit a limited portion of the rhizosphere (15, 24)

Most varieties of *O. sativa* mature within 120-170 days after planting. The period from germination to maturity can be broken into three main stages: vegetative, reproductive, and grain filling or maturation.(25, 111) The vegetative stage begins with

seed germination and continues until the plant produces its maximum number of tillers (secondary stems) (54). The reproductive stage starts with the initiation of panicle primordia (called panicle initiation or "panking") and continues until panicle emergence. During the reproductive stage, tiller number decreases and the flag leaf emerges (44, 55). Grains fill before other panicles have emerged and spikelet maturation (flowering) has occurred. This stage can be subdivided into milky, dough, yellow ripe, and maturity phases (55). The ripening period is sensitive to temperature and varies from 15 to 45 days after anthesis (44).

Constraints to rice production. Constraints to rice production vary by ecosystem and geographical location. According to DeDatta (44), integrated management of herbicides and pests (insects, birds, and weeds) rank number one and two, respectively, as the leading factors for higher yields in irrigated and rainfed lowland ecosystems. Other yield-limiting factors include poor water management, drought, and poor disease control (6-8,56). Upland ecosystems suffer from the same types of constraints to production, but to a lesser degree. Weeds are reported to be the greatest problem in upland rice. Wind competition is reported not to adversely influence the production of flooding rice fields, however, as the submersed upland fields, weeds must be removed by labor-intensive hand-weeding or expensive herbicides (44, 46). Fungal diseases are considered to be the second-most important problem (58) (10,100).

Examples include rice blast, caused by *Magnaporthe oryzae* (Shirai) Sacc. (synonym = *Pyricularia grisea* (Kunze) Sacc.), brown spot, caused by *Cochliobolus miyabensis* (Ito & Kurabayashi) in hot Dacca, in Dacca, south India, caused by *Dreosmythium monensis* (Shah) Desh. and leaf scald, caused by *Magnaporthe oryzae* (Thom)

Insects reduce yields through feeding, and feeding, as well as oviposition, often causes plant damage, such as root injury, stem girdling, and leaf/flower injury (13, 14). Physical symptoms include significant mortality or damage and poor seed fertility. Seeds used for the evaluation of upland rice tend to be white (resulting in 40 and 41 percent), highly weathered and leached, and deficient in N, P, K, and silicon (19, 20, 24, 25).

Rice blast Rice blast is common to every rice-producing region of the world and is the most serious disease of rice in terms of yield loss (2, 10, 13, 24). Rice blast is especially problematic in temperate lowlands, at high altitudes in the tropics, and in upland rice (13, 26). Rice is most susceptible to infection by *M. grisea* as seedlings, during tillering, and following emergence of panicles (2). Generally, infection occurs during vegetative growth in leaves, and during the reproductive phase on seed, seedling, and panicles. Therefore, the pathosystem of rice blast can be split into the leaf blast pathosystem and the seed blast pathosystem (14). Leaf blast causes yield loss by reducing plant height, number of tillers, and the number of ripe panicles at harvest (26). In analysis of yield components by Banerjee et al. (20), the 1000 grain weight and number of spikelets per panicle were most affected by leaf blast, and these reductions were chiefly due to lowered tiller per spike. Seed blast causes yield loss by interrupting the flow of water and photosynthate to developing panicles, resulting in empty or partially filled grains (25, 27). Of the two forms of the disease, seed blast is the most serious with regard to lost yield (13, 24). Banerjee et al. (20) stated that estimated direct yield loss ranges from 0.4 to 1.0% affected panicles annually, and losses from individual spikelets were from 0.0001 to 0.05%.

In the United States, root blight had been of minor importance in all non-growing roots and was not a significant problem until the mid to late 1980s, when epidemics of the disease reduced yields by 10-20% in Arkansas and Texas (36,34,35). Epidemics of blight in the early 1990s in Texas were considered to be the worst in that state's history (36). Root blight was unknown in California until 1989 (37).

Quinn (38), in the 1980s, reported that root blight was the most important of the fungal diseases affecting citrus in Florida. The most serious epidemics of root blight to occur in the United States until that time occurred in Belle Glade in 1952 (41). Currently, the most important diseases of roots in Florida are root blight and brown spot (40, 39). Derisoff et al. (38,41) reported incidences of root blight of 46-75% in untreated test plots. Derisoff and Carroll (39) estimated that reductions of yield and plant quality associated with blight were roughly 30% and 20%, respectively, in Florida.

History and taxonomy According to Pollock (31), root blight was first described in 1784 as *legum* by Thunberg. Reports from Italy by Ascoli (1898), Brignardelli (1906), and Guss (1940) described a disease called *brucce* that likely was root blight (313), although Gu (118) reported that *brucce* might possibly have been another disease or mixture of diseases. The fungal pathogen causing blight was described from diseased root fragments in 1937 by Carter, who named the fungus *Pyrenopeziza myrica*; however, earlier descriptions of the genus by Saccardo consisted an incorrect spelling of the Latin name, therefore under Article II of the International Congress of Botanical Nomenclature, the correct name of the genus is spelled *Pyrenopeziza* (112). The name *Pyrenopeziza myrica* has also been used to describe the root blight fungus, according to Asquith (4), but is pre-dated by *P. myrica* (112).

For many years, *P. cyanea* was believed to be distinct from *Phytophthora grisea* Sacc. despite possessing identical morphological characters (6, 122, 123). Several researchers had suggested that isolates of *P. cyanea* and *P. grisea* were the same fungus, but no consensus was reached until FWO (6, 81, 122). Rasmussen et al. (122) successfully proposed that *P. cyanea* be synonymized with *P. grisea*, with the latter *P. grisea* taking priority. The authors determined that the two were morphologically similar based upon study of type specimens and also by evidence presented by Yaguchi and Udagawa (55) that crosses between *P. cyanea* and *P. grisea* resulted in successful production of the sexual state.

A sexual state of *P. grisea* from soil or other ground was not known until 1971, when Hilsent (87) successfully produced perithecia by crossing two isolates of *P. grisea* obtained from virginians (*Phytophthora virginiana* L.) Hilsent named the new species teleomorph *Clavosporium grisea* (*Myoporiaceae*), but expressed concern that placement into the *Myoporiaceae* was "not clearly indicated" because of the lack of consensus regarding the limits of the family (87). Barr (54) later transferred *C. grisea* to the genus *Myoporia*, which was independently confirmed by Yaguchi and Udagawa (55). The sexual name of the teleomorph of the fire blight fungus was accepted as *Myoporia grisea* (Hilsent) Barr. Barr considered *Myoporia* a member of the *Phytophthoraaceae* (present name *Phytophthoraaceae*) however, Cunniff (21) proposed that a new family, *Myoporiaceae*, be created to accommodate *Myoporia*, *Gaeumannomyces*, *Arthrospila*, *Scopulariopsis*, *Clavosporium*, *Peridermyces*, and *Oosporium*.

Morphology: The monoph of *M. grisea*, *Pyricularia grisea*, has the following characteristics: macroconidia blunt, conocephalous (round), with a mostly subcylindrical growth habit, straight or flattened conocephalium that are pediculate towards the apex and light brown in color; and micro- hyphae that are hyaline. hyaline to pale olivaceous brown, and two septate. Conocephalium typically arrange themselves singly or in groups. Conidia range in size from 15-27 x 3-18 μ m and possess a small basal appendage (45,145). Colonies of *P. grisea* tend to be effuse, grey to olive-green, with numerous mycelia. Chlamydospores are occasionally found (3, 45).

As described by Babari (17) perithecia of *M. grisea* appear singly or in groups, on the stems of a banana. Perithecia are found wholly or partially embedded in the substrate and have long, beaded necks. The base of the peritheciae is dark and globose, with an average measurement of 90 x 400 μ m. Perithecial heads are at first hyaline and later become brown colored. The neck of the peritheciae is lined with deliquescent perispores, and numerous small spores from the base of the perithecial necky and peduncle hyaline, fusiform, three-septate inconspicuous (3,47). A reticulate ring is present at the top of the neck and a pore is evident at the top (17).

Host Range: *Blasopneuste grisea* infects numerous members of the Poaceae, and banana and is be relatively host-specific (6,113,140). Table 1.1 outlines the host range of *M. grisea* (8,83,113-142). The ability of *M. grisea* continues to colonize banana among isolates (1-10,83,145-148). Goto (13) reported that isolates of *M. grisea* obtained from 16 Argentine grass were capable of colonizing rice, while isolates taken from outgroups were limited to that host only.

Pathogenic races The term race refers to pathogenic race (or pathotype) and is used to describe a group of biotypes within a given species that is virulent upon a limited number of host cultivars [1]. In the case of *M. grisea*, races that were pathogenic only to particular rice varieties were recognized as early as 1922 in Japan [2]. By the early 1950s, several sets of differential varieties to separate pathogenic races had been developed around the world. This proved to be elusive in the exchange and comparison relations on international scale, and the United States-Rice Cooperative Research Project was initiated to develop a standardized set of differential materials for international use [3].

A total of 26 race varieties from the U.S., Japan, and 17 other countries were tested, and from those eight were selected to build the international set of differentials. Each differential variety is a "key variety" whose susceptibility to a given isolate of *M. grisea* from the host of eight pathogenicity groups designated A-H [3]. Individual races within a group are numbered and the entire race code is prefixed with an "R" (international). The eight differentials are Kanto (for group A), Koshi (group B), NP-121 (group C), Umi (group D), Dake (group E), Kanto (group F), Kanto-rice (group G), and Caloro (group H). With this classification system, it is possible to separate 316 pathogenic races of *M. grisea* using differentials 1A-1H based on various combinations of reactions and susceptible reactions. A sixth group, I, was added to accommodate race possible race resistant to all eight differentials, bringing the total to 324 [10].

Pathogenic races determined on the differential set using standard procedures for pathogen culture, inoculum preparation, planting, inoculation and evaluation of plants,

and rating of markers in the pedigree. The ratings are constant (X = no marker), moderate (M = small or restricted source) and acceptable (G = well developed genetic source). Because some sets of *M* genes produce intermediate markers in certain differentials, a system was set up allow for the designation of these sets. Lower case letters (a-h), which represent the differential varieties that showed an intermediate marker when associated, are included after the race number (90). Long and Os (90) observed that, while testing pathogenic races of *M. phaseoli* could be partitioned into a equal set of race numbers, the entire population of the pathogen should not be considered to be as tightly structured. By the 1970s, the international race system proved to be inadequate to meet the needs of various worldwide breeding programs, resulting in modifications of the system proposed by Long and Os (90) to meet local needs (18, 62).

Recently, DNA fingerprinting and RFLP analysis have provided greater insight into the relationship among pathogenic races of *M. phaseoli*. In the United States, Levy et al. (39) found that the major pathotypes of *M. phaseoli* were distinguish by DNA fingerprinting, and that the pathotypes could be grouped into distinct lineages. Four distinct fingerprint groups of *M. phaseoli* were found from 113 isolates collected in Arkansas by Xiong et al. (24). In that study, the relatively low genetic diversity of pathogen populations was thought to be a reflection of the limited number of cultures planted in the United States, and it was hypothesized that genetic diversity in populations of *M. phaseoli* would be greater in areas where a large number of race cultures are planted. Levy et al. (38) tested 113 haplotypes of *M. phaseoli* (representing 39 races as identified using the international differential set) collected in a race breeding nursery in Colombia, with the repetitive DNA element (M283H) and found that the isolates could be

pathogen isolates from six distinct lineages. Furthermore, isolates within a lineage were determined to have greater than 90% average nucleotide similarity, and 90% of the pathotypes tested were lineage specific. The majority of the pathotypes tested to be culture specific within a given lineage (33/47).

Genetics. Sexually reproducing strains of *M. grisea* are heterothallic (37,346,358). Compatibility between mating types, *Mat1-1* and *Mat1-2*, is controlled by respective alleles of the mating type locus (TL) (7,346). To date, sexual reproduction has been solely a laboratory phenomenon resulting from crosses between isolates of *M. grisea* on artificial media or sterilized rice straw (37,47,33,35,347). Although the majority of rice isolates of *M. grisea* cannot reproduce sexually (48), Bates and Nottingham (37) successfully produced perithecia of *M. grisea* on greenhouse-grown rice plants following inoculation with an isolate pathogenic to rice.

In nature, *Magnaporthe grisea* as known is reproduced only by asexual means, however, the presence of numerous pathogenic races and high levels of variability have resulted in numerous attempts to identify the mechanisms by which this variability is generated (7,33,35,39,47,343,33,349). Field workers suggested that, in the absence of sexual reproduction, isolation or a parasexual cycle might replace the variability in populations of *M. grisea* (348). Gessell & Ford (317) were able to differentiate 16 different pathogenic races from commercial cultures obtained from single host lesions, and associated with Strickland (338) that parasexuality or mitosis resulted in the variability observed. Parasexual reproduction is a process in which karyogamy, karyogamy, and diploidization occur in the absence of a sexual cycle (3). The existence of a parasexual cycle in *M. grisea* was first established by Gessell and Magill (40) who

proved that typical lesions of identical anastomosis resulted in greater recombination. Recently, microplasmic parasites that exist in a partially diploid state resulting from parasexual recombination have been identified in natural populations of *W. graminis* and have forced researchers to reconsider the importance of parasexuality in the evolution of pathogens [16].

Symptoms. *Microsporum graminis* is capable of infecting culms, leaves, sheaths, panicle sheaths, and panicle branches [15,18,19]. Lesions that appear on leaf sheaths are typically elongated and spindle-shaped with a white to gray-green sporulating center, and on highly susceptible cultivars, lesions may coalesce [15,19]. Older lesions tend to be white-gray in color and possess a necrotic margin [19]. Lesions, and on some cases whole plants, are killed by this pathogen [19].

Belowground by the foot in *W. graminis* are variable and have been reported to include lesions by DRL type 0 or lesions type 1-small necrotic flecks that lack a sporulating center; type 2-small, round to somewhat elongated sporulating spots that exhibit a brown margin or yellow halo; type 3-macro as slightly elongated lesions that are 1-2 mm wide and 1-3 mm in length with a brown margin; type 4-macro spindle-shaped lesions that exhibit a yellow, brown- or purple margin; and type 5-small whitish, grayish, or bluish lesions that rapidly coalesce and lack a distinct margin [14]. Types 1, 2, and 3 are considered susceptible reactions. Lesion type 4 is affected by leaf age and cultivar [79,80,82]. Burman et al. [14] reported that susceptible types/lesions, indicative of a completely susceptible reaction to the host as the pathogen, comprised 80% of the total lesions recorded on the susceptible cultivars 'CQ39', while the percentage decreased to less than 50% on partially resistant cultivars such as 'E254', 'E267', and

While Roussel et al. (1984) found that the number of susceptible-type lesions were nearly constant in older leaves and the number of resistant-type lesions decreased significantly with increasing leaf age.

Infection of scales, root nodules, and periderm by *B. glabra* results in scale black, necrotic lesions called an action scale black (18,118). Infected scale nodules and peridermal regions are typically brown to black and often break at the weakened area. Aporrhesis appears as gray to gray-green bands on infected scales and is most visible during periods of leaf retention, especially during early morning (119,143). If the infection occurs before grain fill, periderm will be white and soft due to girdling of the scales by the fungus, resulting in empty or partially filled grains (18,119). Infections of periderm beneath and outside periderm appear as a lowering or increase in their rates. Cane infected by the pathogen are typically marked by the presence of brown spots on the joints and leaves (118,144).

Aspergillus glaucus produces significant amounts of periderm, a-podolite, and (with dark to white necrotic spots on old leaf tissue), and necrosis, which causes staining of new seedlings (145). Wilson et al. (73) demonstrated that uninfected roots of *B. glabra* infected roots in cells from root nodules that had large numbers of chloroplasts to a higher degree than in cells with fewer chloroplasts, indicating that photosynthetic activity was associated with the occurrence of necrosis.

Epidemiology: In temperate climates, initial infection originates from overwintering structures such as apothecia, spores, or chlamydospores (119,150). Gu (119) reported that mycelium may survive at least five years in soil, and 3-4 years in root nodules. The pathogen also overwinters on the surface of soil (18), and seeds may also

be an important source of viral inoculum (38,93,110). In tropical climates, where rain is abundant continuously, raindrops are the primary source of inoculum (3,10).

Production of virions on leaves occurs at relative humidity (RH) above 80%, with 100% being optimal (34). Sporulation is greatest at dusk and early morning, when humidity levels are optimal (140). Sporulation has been reported over a range from 15-23°C; however, optimal temperature for sporulation is 23°C (34, 110). Clouded release requires the moisture and mechanical dissemination of virions at greater above 100% relative humidity. Rainfall and wind facilitate spore release (109,143). Long range dispersal of virions is possible via wind, water, transport of infected stems, and movement of virions-bearing sand (11,140).

Upon contact with plant surfaces, sporangia are released from the periplasmic space at the tip of the sporangium, which serves as an adhesive to anchor the sporangia to the substrate (11,71,144). Root exudates on plant surfaces is required for germination of virions, differentiation of appressoria, and the establishment of infection by *M. grisea*. As periods of leaf moisture are reduced depending on temperature, infections are reduced (11,140). At 12°C, leaf wetness periods of 11-20 hours are needed for infection, while at 20°C, 4 hours of wetness are sufficient. Once taken up through stomata, followed by formation of appressoria. Optimal temperatures for appressorial development are between 10°C and 20°C. Temperature increases in contrast with dew produce a positive effect the ability of *M. grisea* to infect rice (94,110,143). At 20°C, dew periods of 6-8 hours are sufficient for infection.

The appressorium adheres to the host, a sporangium and produces a penetration peg that enters the host via apothelial penetration or cuticular (5,145). The wall of the

approximation acts as a mechanically portable membrane that allows an influx of water molecules, generating turgor pressure as high as 1 MPa (100 l per). These forces have been demonstrated to be sufficient to force protoplasts past one another, as well as into artificial membranes of varying thickness (15,16). Dehydration of a nucleus layer, roughly 100 nm thick, immediately extends the plasma membrane of the approximation has been shown to facilitate target uptake. Microinjection contact of the fungus on completion of establishing infection in rice leaves (71,146). Once inside epidermal cells, target hyphae differentiate from a vesicle produced by the penetration peg, and multiply intracellularly and intercellularly within the host (104-145).

Inoculation period (time between infection and visible symptoms) and **latent period** (time between infection and sporulation) in the *R. grisea*-rice pathosystem are largely temperature-dependent (12). Typically, symptoms appear within 4-9 days and sporulation begins about immediately afterwards (105,124). Latent period varies with temperature, and can range from 4-8 days at 26-28°C and to 7-9 days at 12-14°C (118,103). Latent period was also shown to vary among cultivars by Chakrabarti (25), while Korman (122) found no significant differences in latent period among six partially resistant cultivars grown under tropical conditions.

Factors limiting disease—Inoculum and severity of rice blast are influenced by environmental factors such as water level, soil fertility level (nitrogen and silicon), or temperature and humidity (11,76,107,110,142). Rice grown under aerobic conditions, such as upland rice or tilled lowland rice with infrequent flooding, is more susceptible to infection by *R. grisea* than rice grown under upland conditions (12,113,103). Hatanaka (66) noted that severity of rice blast was inversely proportional to soil moisture and

demonstrated that tiller and resistance was correlated with poor silicon uptake, based on analysis of tiller tissues, and low leaf sugar contents (resulting in less resistance to penetration by *M. grisea*). Susceptibility to blast also is influenced by the leaf age, with older leaves tending to be more resistant to infection than younger leaves (75, 76).

Excess nitrogen (N) fertilizer has been implicated as a predisposing factor of rice to blast (66, 67, 77). Because rice that is more stress or young, has hardened tissues (78), excessive N was believed to augment severity of blast by increasing the amount of new growth (76, 78, 79). Senoli (75) noticed a increase/balance in greater resistance of the epidermis of rice leaves to penetration at several levels of N fertilization and found that resistance to penetration was lowest at the high level of N, indicating a reflection in the breakdown of epidermal cells. Researchers have suggested that high levels of N alter the amounts and types of nitrogen-based compounds present, and that this influences host susceptibility to infection by the fungus (78). Chiba and Kuroki (80) found high levels of soluble N in leaves that had been over fertilized with N and proposed that *M. grisea* could use soluble N as a nutrient source. Recently, Otero Castañeda (81) determined that levels of rice blast were consistently higher in plants that received nitrate (NO_3^-) as compared to plants treated with ammonia (NH_3). Interestingly, nitrate is the form of N present in splend rice soils, while ammonia is the dominant form in flooded soils (82). For these reasons, Otero Castañeda (83) suggested that the form of N was a more important factor in the susceptibility of rice to blast than the presence or absence of flooded conditions.

Development of rice blast is also affected by relatively mild or a night, long periods of light stimuli as day, and nocturnal temperatures in the range of 17-27°C

(11,114). Low nitrogen light levels, due to vertical stems, also increase selection efficiency of *M* genes, resulting in greater severity of disease (64).

Resistant cultivars. The planting of resistant cultivars is the preferred means to manage rice blast because numerous pathogen races and high rates of variability within pathogen populations have rendered many resistant cultivars ineffective within 2–5 years after release for commercial use (33,34,115). Difficulties among cultivars were widely recognized by Japanese scientists in the late 1920s, but systematic breeding programs were not initiated until 1929 (79). In the United States, breeding for resistance to blast did not begin until the 1940s, but the first introduction of cultivars with resistance to blast was made in 1959. By 1973, Matall observed that there were no cultivars with no longer sources (7). In Colombia, blast resistant cultivars that were released in the 1950s and 1970s became susceptible to *M* genes within a few years after introduction for commercial use (25). One cultivar, Com 6, failed after a single growing season in both Colombia and other Latin American countries (11).

Rice breeding strategies based on vertical resistance until the mid-1970s (33,34,116). As defined by Vasilevskii (34), vertical resistance, also called race specific or major gene resistance, is monogenically inherited, insensitive to the environment, and its expression is qualitative ("all or nothing") (33,116). Using differential cultivars and linkage analysis, researchers have identified 13 dominant alleles (called *P* genes) for resistance to rice blast at eight loci (31,117). A gene-for-gene relationship exists between *M* genes and *P* genes, conferring resistance to the host against pathogen races with avirulence (*avr*) genes that correspond to *P* genes in the host (33,117). Typically, rice plants with vertical resistance to a particular race of the

pathogen exhibit a hypersensitive response when challenged (33,113). The short-lived nature of natural resistance is explained by the variability in populations of the pathogen (33,113). Natural resistance affects epidemics of rice blast by reducing initial disease (I_0) (113,147).

Difficulties in breeding for race-specific resistance have led researchers to examine horizontal, or race-reducing, resistance, to the rice blast disease (34). In Japan and the United States, rice breeders observed that rice cultivars possessing identical major genes showed different resistance to *BL* grown in the field and termed this phenomenon "field resistance" (34,112,142). This type of resistance was considered to be polygenously controlled, suggesting that field resistance was similar to natural or horizontal, or partial, resistance (34). Horizontal resistance, where Vanderplank (347) made quantitative effects on disease but neither incomplete resistance to all races of a particular pathogen. Because horizontal resistance is under polygenic control, it is likely to be most difficult for new pathogen races to overcome this type of resistance. However, the very nature of polygenic inheritance makes breeding for horizontal resistance is much more challenging task (33,113). Also, selection for horizontal resistance is complicated by race-specific resistance, which masks the effect of the horizontal resistance (112,124). Evidence for the role of multiple genes in horizontal resistance of blast in disease has accumulated in recent years. Small groups of genes, called quantitative trait loci, have been mapped in the genomes of partially resistant (horizontally resistant) cultivars that confer horizontal resistance to rice blast (37).

The effect of horizontal resistance on epidemics of rice blast in the collective or epidemic rate (R_0) giving rise to the epidemic 'race-reducing resistance' (114,147).

Parkehalil (114) identified several components of resistance that serve to reduce τ , such as low infection efficiency, lengthened latent period, reduced lesion size, shortened infectious period, and reduced sporulation per lesion. In the rice blast system, the most important component of hereditary resistance was shown to be infection efficiency, defined as the ratio of colonies to sporulating lesions (3,112, 113).

Race-nonspecific resistance, while more durable than race-specific resistance, is considered less effective than race-specific resistance and is sensitive to the environment. According to Zengler (112), this type of resistance is better suited for use in temperate regions or regions where ideal disease conditions are not constantly present. A more durable type of resistance in rice blast has been reported in Colombia in certain cultivars that were selected and advanced in the presence of a highly diverse population of *id* genes (14,11,114). A commercially planted cultivar, Oryza Liana 5, was developed at a rice-breeding station in western Colombia where segregating populations were grown under optimal conditions. Breeding lines were screened by "spreaders rows" composed of mixtures of commercial cultivars and sources of resistance to *mycelia-in-ovo* pathogen populations and high levels of resistance (14,11,115). During the selection process, genotypes that were spontaneous or exhibited extreme hypersensitiveity were rejected, to insure that quantitative trait loci that conferred partial resistance were advanced along with major genes for resistance (14,11,116,117). One product of this breeding program, the commercial cultivar Oryza Liana 3, has been recognized as HRP and is still highly resistant to rice blast (16).

Fungicides Fungicides are effective for the control of both local and weak blast of rice. They are most commonly used as seed treatments, tillage sprays, or granules for

publicly applicable to high-input, rice-cultures systems in Japan, South Korea, Indonesia, and China (15,34, 118,143). Fungicides are used less frequently in Vietnam, Cambodia, Laos, Latin America, the United States, and India due to low natural severity of disease, low crop value, or high cost to benefit ratios for chemical protection (34).

Copper fungicides, such as the Bordeaux mixture, were among the earliest employed to control rice blast, but they were ineffective during various epidemics of blast (15,118). Copper compounds proved to be phytotoxic to the rice plant and caused yield losses, especially in warmer climates (118). Organotinorous fungicides were successfully used as dusts and sprays to control rice blast in Japan from the late 1930s until the mid-1960s, but were withdrawn from the market because of environmental and health concerns (118). Organophosphorus compounds emerged in the mid-1950s for the control of blast and panicle or rice borer (34). Isoprothiolate and edifenphos are currently registered in Asia and Latin America for the control of rice blast, and are used in preventive and curative rates (33). Brazil shows a high level of residual severity, but the systemic activity of isoprothiolate is greater than that of edifenphos. Frey et al. (33) reported that a spray application of edifenphos (at 0.15 kg/ha) made at heading reduced neck blast by 37% as compared to an untreated control, while applications made at flowering and early heading reduced neck blast by 17%. Isoprothiolate and edifenphos suppress mycelial growth by disrupting the metabolism of phosphatidylethanolamine, a key step in the biosynthesis of phospholipids in *M. grisea* (33). Resistance to strains of *M. grisea* to organophosphorus fungicides has been reported in laboratory tests and in commercial fields (34).

Antibiotic compounds, such as blasticidin S, derived from *Streptomyces griseoflavus* sp., and kasugamycin, derived from *Streptomyces kasugaensis*, have been used in Asia and Latin America for the control of rice blast because of their oxidative properties (34,35). Although Yanagisaki (35) reports that blasticidin and kasugamycin are highly effective against *M. grisea*, neither generally have proved to be moderately effective at least for blast control (34). Antibiotic isolates retarded growth by blocking the incorporation of amino acids during protein synthesis. Resistance to both blasticidin S and kasugamycin has been reported in commercial fields (34).

A more modern class of fungicides, the melanin biosynthesis inhibitors (36), have emerged as potent controls for rice blast. All MBIs fungicides are strongly systemic (translocated in the xylem) and have a high degree of residual activity (34). Additionally, MBIs fungicides are selective against *M. grisea* and do not affect other pathogens common on rice. These compounds are not fungicidal and act to inhibit penetration of *M. grisea* into the rice plant by blocking the biosynthesis of melanin, an important component of the appressorial wall (3,32). Three MBI fungicides (pyraclostrobin, pyrocyprodin, and tritide) are currently registered for use in Asia and Latin America. Frey et al. (32) reported that a single spray application of pyraclostrobin, made at heading, reduced rice blast by 93%, and applications made at heading and early heading reduced rice blast by 93% when compared to untreated controls. MBI fungicides, particularly tritide and pyrocyprodin, have been shown to be effective against leaf and neck blast when applied as seed dressings (32,33). Filappi and Prabhu (33) reported that pyraclostrobin, applied as a seed treatment, delayed the appearance of leaf blast until 42 days after planting, as compared to 40 days for the untreated control, and was quite effective in

manage long term management when utilized in conjunction with partially resistant cultivars. Despite the specific mode of action of DMF fungicides, resistance to these compounds by *U. phaseoli* has not been reported.

Benlate, a benzimidazole compound, is the only fungicide registered for the control of rice blast in the United States and is not used elsewhere due to the availability of superior chemicals abroad (33,54). This fungicide is transported systemically to plants (37). Benlate inhibits apical growth and sporulation by binding tubulin disrupting the movement of chromosomes during mitosis and meiosis (44). Resistance to benlate by fungal pathogens has been reported in numerous pathosystems (44,47). Because the mode of action of benlate is highly specific, single resistance within populations of fungal pathogens can result in the occurrence of benlate-resistant strains.

Fungicides affect spore germination of plant diseases by reducing the amount of initial inoculum (x_0), the rate (r) at which the epidemic progresses, or both (3,27).

Applications of fungicides that suppress or eradicate existing inoculum, or prevent the arrival of inoculum tend to delay the onset of disease, while applications made during the course of an epidemic reduce production of spores and thus the rate of progress of the epidemic (1,2). Fungicides also may be utilized to accomplish horizontal resistance of crop plants. Fry (56), for example, reported that the amount of aboveground necessary to support *Phytophthora blight* on potato was significantly less for cultivars with horizontal resistance to late blight than for cultivars with no resistance to the disease.

Cultural practices: Rice that can be managed by several cultural practices. Early seeding and transplanting in Asia and Thailand have been shown to reduce the severity of rice blast by allowing plants to develop at a time when conditions are not

optimal for blast development (13,40). Because drought stress is known to increase the severity of rice blast, good water-control and irrigation practices help lessen the impact of the disease (22). Reduced rates of seeding lower the overall population of plants in an area and slow the development of rice blast (24). Removal and destruction of crop residues is an effective means to reduce the amount of viral inoculum present to infect subsequent crops (34,37).

Maintenance of adequate levels of essential plant nutrients such as nitrogen, potassium, phosphorus, and silicon has been shown to aid in the control of rice blast (11,45) (16,37). Excessive amounts of nitrogen fertilizer have been shown to exacerbate the severity of rice blast, although the amount that defines 'excessive' varies by location, soil type, residue culture (15,45). The severity of rice blast can be reduced by reducing the rate of nitrogen applied, or by altering the timing of nitrogen applications (3,34). Kurekawa *et al.* (34) demonstrated that high levels of nitrogen could be applied to rice without increasing the severity of rice blast with multiple applications of fertilizer at lower rates. They also noted that a delayed application of nitrogen was also effective in reducing the severity of rice blast. Over-fertilization of rice with phosphorus and potassium has been implicated in increasing the severity of blast on certain soil types (15,31).

Silicon. Silicon (Si) makes up 21% of the earth's crust and is the second most abundant element in soils and forms numerous mineral compounds (71,117,34). Silicon is taken up by nearly all plants, which use silicon, depending upon the species, between < 1% to greater than 10% of total biomass (47,50). As a group, dicots have the lowest Si content (roughly 0.1%), dicotyled green (alfalfa, oat, rye, sorghum) contain about 0.6-3%

and aquatic plants, such as rice, have the highest (>2%) Si content (30, 33). Plants can be considered "silicon accumulators" if their dry weight concentration of Si is greater than 1% (30). In plant species such as *Oryza* and *Equisetum*, the uptake of Si equals or exceeds that of essential nutrients, such as nitrogen and potassium (76, 127). According to Epstein (30), the inclusion of Si among essential plant nutrients for all plants is not supported by evidence in the literature; however, species such as *Equisetum* and some algae cannot survive without adequate Si.

Rice plants are capable of survival in low-Si environments, but exhibit reduced lodging, poor tillering, and lowered yields (41, 127). In soils where Si is limiting, the addition of Si fertilizer has been shown to dramatically improve growth and yields of crops such as rice and sugarcane (42, 59, 123, 127). The systematic benefits of adequate Si to rice were first recognized in Japan (41, 127). The application of Si-based fertilizers to improve plant nutrition has become commonplace in Japan and also in the Florida Everglades Agricultural Area (39). In rice, Si is beneficial because it promotes available phosphorus in soil, reducing uptake of phosphorus, improving water use efficiency (mainly reduced transpiration), reducing lesions associated with Mn, Fe, and Al, increasing mechanical strength, improving growth habit (which increases photosynthesis area), and reducing shading of grass (41, 49, 92, 127).

In addition to agricultural use for growth by increasing adequate levels of Si in the rice plant, numerous researchers have reported that the application of Si to soils or water deficient in silicon, plant available Si reduces the incidence and severity of several important diseases of rice (43-45, 47, 81, 123, 126, 132, 140). Suzuki (127) reported that the resistance of rice plants to infection by *As* grass was enhanced by applications of Si to

gently soils. Wada et al. (191) determined that the number of lesions caused by *B. glabrata* on leaves of 'Coloso' rice decreased linearly as the Fe content in leaf blades increased. Rajendran et al. (116) found that the content of Fe in leaf and seed tissue varied among four different cultivars of rice grown under identical conditions, and that those cultivars with relatively higher content of Fe had less incidence of leaf and seed blast. Other reports indicate that cultivars of rice with relatively higher levels of Fe in tissue are not always more resistant to blast than those with lower inherent levels of Fe when grown under the same conditions (23,118,121). However, for a given cultivar grown under varied levels of Fe fertilizing, susceptibility to blast is nearly always correlated with the content of Fe in the plant (23,119). Resistance to blast is not solely mediated by the concentration of Fe in the rice plant, but is also a function of genetic or environmental factors (23,119).

Arshin et al. (24) demonstrated the ability of inorganic and organic silicon compounds to reduce rice blast. In their study, the application of various sources of Si decreased the incidence of rice blast by nearly 50% when compared to untreated plants. Chinniff et al. (25) applied soluble silicate slag (30% Si as Si) on silicon-deficient *Hydrangea* in southern Florida at rates of 0, 2, 4, and 11 T/ha and reported significant reductions of neck blast. They found significant linear and quadratic relationships between slag applications and both disease reduction and increased yield as well as increased silicon content 1 year after application. Other studies conducted with soluble silicate slag revealed that finely ground material was more effective than more coarsely ground grades in reducing the incidence and severity of neck blast (21). The use of fine grade slag was also correlated with higher silicon content in the plant and increased yields. Chinniff and

duplex (40) demonstrated that reductions in the severity of neck blast brought about by the application of 400 kg of Ss ha⁻¹ did not differ significantly from those achieved by applying a labeled rate of benzoyl.

In upland rice, Yatsuda and Watanabe (154) reported that the addition of sodium silicate to Ss-duplex soil from Nigeria decreased the severity of neck blast on direct sowings of rice by 40%. Watanabe (155) reported that the addition of sodium silicate to Ss-duplex soil in Nigeria reduced the severity of neck blast by over 30% as compared to non-treated controls on eight different genotypes of rice. The application of Ss at 300 kg/ha to Ss-duplex soils in eastern Colombia reduced leaf and neck blast by 40% and 73%, respectively, as compared to rice cultivated with Ss (33). Sanford et al (128,132) assessed soils known to be deficient in Ss in eastern Colombia at concentrations of 400 or 1200 kg of Ss ha⁻¹ and found that the severity of leaf and neck blast was reduced between 18 and 40%, depending upon the location and rate of Ss.

Other diseases of rice reported to be controlled by silicon applications include brown spot, caused by *Cochliobolus miyabeanus* (synonym *Helminthosporium oryzae* Boodh de Haan), which is caused by *Helminthosporium oryzae* (synonym *C. miyabeanus*) [Hirakawa & Takagi, W. China], sheath blight caused by *Phenanthrophora oryzae* (synonym *Helicostoma oryzae* Kuhn), sheath rot, caused by *Helminthosporium oryzae* Calt. (synonym *Sclerotinia oryzae* Calt.), bacterial spot, caused by *Corynebacterium* A. *terrestris* [and grain discoloration, caused by a complex of insects and fungi (24,42,43,47,48,54,126,137,139,139)].

Control of damage to other crops by Ss has been reported. Potassium or sodium silicates have been applied to surrounding natural vegetation and foliage to control

primary outbreak of mealybugs and scale insects caused by *Sphaerostromia filipes* (Belokobyl'skiy) (Pellaea), and to reduce the severity of crown and root rot of mealybugs caused by *Phytophthora blight* (P. blight). Primary outbreaks of mealybugs caused by *Phytophthora blight* (P. blight), and of scale, caused by *Phytophthora blight* (P. blight), are also known to be suppressed by the application of Zn to foliage or soil (246). Horvath et al. (19) reported that foliar applications of Zn significantly reduced the number of colonies of *Phytophthora blight* (Belokobyl'skiy) (P. blight), caused signs of grape powdery mildew, or mealybug on grape leaves. Potassium and sodium chloride are regularly applied to vines in European vineyards to suppress powdery mildew (11). The presence of sodium in vine plants has been associated with reductions in damage by mealybugs on soil (27). It is reported that Zn acts mechanically to block penetration by styles of sucking insects, and deposits of Zn on vine leaves have been shown to wear down mouthparts of sucking insects (27,28). Soluble sodium plant sap has been observed to be feeding deterrent to phloem-sucking insects present at concentrations of at least 0.04 applied (29).

Mechanisms of Zn-induced resistance in rice blight. Suzuki (157) determined the susceptibility of rice plants to infection by *M. grisea* was correlated with the thickness of the waxy layer beneath the cuticle, and the number and thickness of epidermal cells and stomata. He found that there were significantly more released hydrolytic, long, and short cells in the epidermis of Zn-resistant rice cultivars. Leading him to conclude that deposition of Zn acted as a physical barrier to penetration by *M. grisea* (157). The physical barrier hypothesis is strengthened by the findings of Nishida et al. (168), who reported that a layer of silica gel approximately 2.5 µm thick is present

beneath the cuticle of rice leaves, sheaths, and stems. The authors argued that the "cuticle-like debris layer" and suggested that it might serve to inhibit the establishment of infection by *M. grisea* by a physical blocking of the entrance of penetration pegs or by prevention enzymatic-degradation of the epidermis (345). Voth *et al.* (346) hypothesized that Si might form complexes with organic compounds in the walls of epidermal cells that resist degradation by enzymes released by penetration pegs of *M. grisea*. The presence of Si was detected in lignin-carbohydrate complexes from epidermal cells of rice that had been grown in a Si-rich solution by Iwasaki *et al.* (347). Brown *et al.* (348) demonstrated that the establishment of infection by the rice blast fungus was mediated by both lignin precursors and enzymes. It was observed that application of *M. grisea* penetrated larger pores and sufficient to force penetration pegs through a 10 μ m film of a thickness and hardness approximately equal to host cell walls, and that more time was required for the penetration of the aseptate films than for seed surfaces. The authors suggested that enzymatic-degradation of the epidermis, combined with extensive target tissue, were responsible for the more rapid ingress into leaves as compared to aseptate films, and that the presence of Si in epidermal cells might add to the hardness of rice leaves and increase resistance to penetration by *M. grisea*.

Experimentation with several host-pest systems has provided evidence that Si is involved in the expression of pathogen-induced host defense responses. The failure of application of Si to promote the epidermis of barley has been correlated with the accumulation of deposits of insoluble Si directly beneath the epidermis in question (29). Minchin *et al.* (349) reported that, following inoculation with *F. fuliginea*, phenolic defense compounds appeared more quickly and in greater quantity in epidermal cells of

Si treated nurseries plants than in plants not treated with Si. The accumulation of electron donating phenolate compounds in roots and hypocotyle of Si treated nurseries plants following inoculation with *Pythium ultimum* was detected by Choud et al. (23) using energy dispersive X ray analysis. Visible differences were found in the accumulation of these compounds between Si treated and untreated plants and these compounds were not present in Si treated plants prior to inoculation. In a separate study, Choud et al. (24) found that nurseries plants treated with Si exhibited increased and more intense activities of ribonuclease, proteinase, and polyphenoloxidase after inoculation with *P. ultimum* than plants not receiving Si. Phenolate compounds extracted from Si treated plants were strongly fungistatic against *Pythium* spp. in vitro. Silica may play a similar role in the resistance of rice plants to blast; however, an experimental evidence has been produced to date.

Uptake and forms of Si in the rice plant Silica is present in soil as monosilicic and polysilicic acids or Si adsorbed on or precipitated with oxides of Al, Fe, and Mn, as well as as silicate minerals (34,37,42). However, the form taken up by plants is exclusively monosilicic acid (H_2SiO_3). Intake of monosilicic acid to plant roots is driven by diffusion and by the influence of mycorrhizae induced root elongation (root flow) (47). Members of the Poaceae have been shown to take up Si at rates equal to the rate of plant transpiration (18). The concentration of monosilicic acid in xylem sap of grasses has been demonstrated to be equal to that of the soil solution, however, some herbs, such as common clover, appear to exclude monosilicic acid selectively at the root level (18).

In the case of rice, the amounts of silicon found in plant parts cannot be explained fully by diffusion and transpiration alone (47). Researchers have reported that the concentration of Si in the xylem is usually many times higher than that of the soil solution, and that the uptake of Si in this case is metabolically driven (87,90). Rice roots have been shown to concentrate monosilicic acid against a concentration gradient via processes associated with nitrification and glycolysis (47). By using metabolic inhibitors it was shown that Si uptake and transpiration presented at different rates and that transpiration was affected more by than uptake shown. Additionally, monosilicic acid was absorbed equally well in light and dark conditions (76).

Over 90% of the total Si in the rice plant is in the form of hydrated silica (SiO₂·nH₂O) referred to as lignified opal (90,100). The remaining portion of Si is in the form of monosilicic acid, colloidal silica, acid, or organosilicon compounds (47,71,127). Deposition of Si in epidermal cells and cell walls occurs when the concentration of monosilicic acid exceeds 8 mol m⁻³ in a particular tissue (107). Silica tends to be distributed homogeneously and is less concentrated in younger leaves than in older leaves (90,51). High levels of Si in older leaf tissues are believed to be partly responsible for increased resistance to rice blast (78,83,114). The majority of Si accumulated by rice plants is deposited in leaves (71% of total), followed by hulls (12%), roots (10%), and stems (8%) (97). Once deposited, silica gel is made of Si and is not redistributed to actively growing tissues (47,91).

Factors influencing the availability of Si in soil. The availability of Si is affected by soil environment. McLaughlin and Clark (76) reported that the amount of available Si decreased with increasing pH in a wide variety of soil types and textures. The

average concentrations of soluble Si in soils were shown to be 35 ppm and 5 ppm at pH 5 and 8 respectively. This evidence directly substantiated the behavior of Si in water solutions, where it has been shown that solubilities remain stable (100-140 ppm) at pH 2-8, but sharply increase above pH 8 (79,80). Apparently, at neutral pH, Si precipitates from solution at concentrations above 140 ppm, while solubility is increased above pH 8 due to the formation of silicate ions (78).

McKenney and Chase (81) reported that the concentration of Si in soil solutions is controlled by a pH-dependent reaction whereby amorphous (or particular Al oxide) silicate minerals react. This reaction has a strong effect on the solubility and availability of Si in plants. At conditions of low soil moisture, the increased water potential makes uptake difficult by the plant, plus there is less water available as a solvent in the soil solution. Plant uptake of Si increases with increasing water due to both an increase in solution uptake and an increase in Si in solution (78). Additionally, researchers have indicated that Si content increases in flooded soils, possibly due to an increase of organic acids under the reducing conditions characteristic of submerged soils. These acids then dissolve silica. Some evidence exists for the increased release of Si from Fe-Si complexes (78).

Interactions with elements such as P and Al also have an effect on the availability of Si in soil. Runkenberg and Wedinoid (117) demonstrated that soil phosphorus, in the form of orthophosphates, had no effect on the release of Si into soil solutions. Increasing amounts of phosphate added to various soil types and conditions resulted in decreasing amounts of Si dissolved in solution. The authors hypothesized that Si and P compete in soil for binding sites, and soil is affected by clay minerals. Si is released. This reaction was

also found to be reversible by the addition of natural silicates, and this is believed to be the underlying mechanism for the enhanced availability of P from in situ biological soils (117). Interactions between Al and Si also have been noted. Aluminum oxide, compounds, or ions is known to adsorb monosilicic acid in soils at levels that increase with increasing soil pH (78). Also, the concentration of Al (and Fe) compounds is positively correlated with Si solubility.

Silicon-deficient soils. Depletion of the abundance of available Si in most natural soils, deficient in plant available Si, may occur due to depletion from continuous plowing of rice (17). The uptake of Si by an average rice crop has been estimated to be roughly 250–400 kg/ha, and intensive cropping results in the removal of Si from the soil at twice as a rate faster than it can be replenished naturally (17). Deficiencies in plant available Si are also common on soil types such as Oxisols and Ultisols, the soils commonly planted in upland rice in Asia, Africa, and Latin America. Heavy erosion on these soil types results in high degrees of weathering, leaching, redistribution, and desilicification (117,144). Alluvial soils in organic matter content of greater than 80%, and thus low mineral content, are also deficient in plant available Si (106). Soils which have a high content of quartz sand (SiO_2), are also low in soluble, plant-available Si (19).

Sources of Si fertilizers. Colloidal silica (Celsolysilaps), which are byproducts of one production or phosphorus fertilizer manufacturers, are commonly applied to rice in Japan and Florida, and to sugarcane in Florida and Hawaii (43,61,136). Zeolite-based, a naturally occurring form of calcium silicate, also is used to increase the concentrations of Si in soils. Composted and raw hulls have been reported as sources of Si, however, the percentage of Si per unit of volume is considerably lower than the clay and zeolite-based

and large quantities of crop residues will now have to be used to replace a comparable amount of N in the soil [47].

CHAPTER 18 EFFECTS OF SILICON AND PESTICIDE TRENDS ON DISEASE CONTROL, YIELD, AND YIELD COMPONENTS IN UPLAND RICE

Introduction

Upland rice (*Oryza sativa* L.) is cultivated globally on approximately 28 million hectares of soils characterized by various weathering and leaching (43,64,114). These soils, Ultisols and Oxisols, tend to be low in base saturation, high in accumulated iron and aluminum oxides, highly acidic, and low in plant available silicon (134,136). Other soil types reported to be silicon deficient include Histosols—the type found in the rice growing areas of southern Florida, and some Entisols (42,43,136).

Silicon, a major constituent of the earth's crust and the second most abundant element in agricultural soils, is not listed among those typically considered to be necessary for plant growth. Regardless, silicon can account for up to 30% of the total biomass for various plant species (41,50). Rice plants that have access to soluble silicon often exhibit improved growth, resistance to diseases such as rice blast and leaf scald, resistance to insect feeding, improved nutrient use, and reduced nutrient toxicity (41,50,123,136).

The production of upland rice is limited severely by diseases such as rice blast, caused by *Magnaporthe grisea* (Roberts) Bar and leaf scald, caused by *Chlorophyllum allantos* Thum. (5,34). Green discoloration, a permanent problem resulting from a complex of fungi and insects, reduces overall yield quality (47,132). In recent research,

the application of volcanic ash, as a source of plant available silicon, to silicon-deficient soils reduced the incidence and severity of rust that, decreased grain discolouration, and increased yields of upland rice (Añón, 2011, 2012). (Zinell et al. 2011) applied silicon to silicon deficient soils in southern Florida and found that only that condition reduced to the same levels achieved by applying boron.² The purpose of this study was to determine if applications of volcanic ash plus commonly-used fungicides applied at specific growth stages of the rice plant could control blast and leaf scald, and to determine if applications of these fungicides could be reduced or eliminated. Yield and grain quality of the various treatments were also assessed.

Materials and Methods

The experiment was conducted in eastern Colombia at CIAT's Santa Rosa Experiment Station and the Mixalilil Farm in Allaflore, two areas with soils known to be silicon-deficient. The experimental design at both locations was a randomized complete block with five replications and a plot size of 6.34 × 6 meters. Silicon (Si), applied as wellbourne (K₂SiO₃ at 2.7 t ha⁻¹ (400 kg of elemental Si ha⁻¹), was incorporated into plots 3 days before planting with a moulder. The blast susceptible variety Oryza 1 was planted at Santa Rosa, and Oryza delaware, also blast susceptible, was cultured at Mixalilil. The seeding rate at both sites was 80 kg ha⁻¹.

The treatments included a control (no Si and no fungicides), Si applied alone and Si plus either chlorpyrifos (Dowco 35 EC, Bayre AG) or imazaliquin (Fungo 75 WP, Dowthron) applied at two schedules that included one or more of the following growth stages of the rice plant: tillering (T), panicle initiation (PI), heading (H). PI panicle emergence (PE), and HH panicle emergence (HH) (Table 3.1). In terms of days after

Table 3.1. List of treatments applied to rice at Santa Rosa and Manací, Colombia in 1994. Each treatment is a combination of tillage (S) or no-till plus either azoxystrobin or tricyclazole applied at specific growth stages of the rice plant.

| S ^a kg ha ⁻¹ | Fungicide used and timing of application ^b | | | | |
|---------------------------------------|---|--------------|--------------|--------------|--------------|
| | Tillering | Initiation | Heading | Grainling | Graining |
| 0 | - | - | - | - | - |
| 400 | - | - | - | - | - |
| 400 | azoxystrobin | azoxystrobin | tricyclazole | tricyclazole | tricyclazole |
| 400 | - | azoxystrobin | tricyclazole | tricyclazole | tricyclazole |
| 400 | - | - | tricyclazole | tricyclazole | tricyclazole |
| 400 | - | - | - | tricyclazole | tricyclazole |
| 400 | - | - | - | - | tricyclazole |
| 400 | - | - | - | tricyclazole | - |
| 400 | - | - | tricyclazole | - | - |
| 400 | - | - | tricyclazole | tricyclazole | - |
| 400 | - | azoxystrobin | - | tricyclazole | - |
| 400 | azoxystrobin | - | - | tricyclazole | - |

^aSanta Rosa. Azoxystrobin was applied at 20, 70, 110, 150 and 190 days after sowing for the tillering (T), panicle initiation (PI), heading (H), 10% heading (10%), and 50% heading (50%) growth stages, respectively. Additional fungicides were applied at 25, 60, 70, 79 and 83 days after sowing for the T, PI, H, 10% and 50% growth stages, respectively. Azoxystrobin (1 L ha⁻¹) was used for cyclopropanes made at T and PI while tricyclazole (800 g ha⁻¹) was used for applications made at H, 10% and 50%.

^bAt early growth stages ¹ indicates an application made

seedling (DAS) applications were made at the following ranges: tillering applications at 15 DAS, panicle extension applications at 34 DAS, heading applications at 63 DAS, 15% heading applications at 82 DAS, and 50% heading stages at 99 DAS at the Santa Rosa site. At Mazatlán, applications were made at 15, 45, 75, 75, and 83 DAS, respectively, for the same growth stages. Fertilization was applied at 1 L ha^{-1} for the control of leaf blight for those schedules that required applications of fungicide at tillering and panicle initiation. Tricyclazole was applied at 300 g ha^{-1} for the control of neck blight for those schedules that required applications of fungicide at heading, 15% heading, and 50% heading. A initially preirrigated backpack sprayer, in which constant pressure was maintained via installation of a lower speeded pump, was used to deliver both fungicides at 275 L ha^{-1} of water.

Leaf blight was estimated during the tillering stage by evaluating five leaves for the percentage of dollar spot damage at five locations within each plot. Disease evaluations were made at 42, 46, 54, and 61 DAS at Santa Rosa, and 41, 54, and 61 DAS at Mazatlán. Neck blight was assessed at 25 and 33 days after flowering as percent disease incidence of 20 panicles per plot. Severity of leaf and/or neck blight was determined at the same season as leaf blight immediately after appearance of symptoms, evaluations were made at 81, 82, and 99 DAS at Santa Rosa and at 71, 82, and 99 DAS at Mazatlán. Severity of leaf blight and yield were used to construct area under disease progress curves (AUDPC) for all treatments. Analysis of variance (ANOVA) was performed on AUDPC values and neck blight data, and Fisher's protected least significant difference test (LSD) was used to separate means.

In each plot, a 4 m x 6 m area was harvested by hand and used to determine the yield of rough (unfilled) ears per hectare. Plants were adjusted to reflect 17% moisture content. The number of filled grains/plant to which the caryopsis was entirely occupied by the endosperm per 10 grains was determined. Grain discolouration was rated using the IGRD (artificial scale, where 0 = grain with no discolouration and 5 = completely discoloured grain) (74).

Results

Leaf and neck blight. Applications of silicon (Si) successfully reduced leaf and neck blight severity at Santa Rosa and Matamoros with and without inputs of fungicide. At the two locations, severity of leaf blight for those plots amended with Si either alone or with a single fungicide application was generally lower than those for the untreated control (Fig. 3.1). Area under the disease progress curve (AUDPC) of leaf blight was lower for Si alone (P=0.05), and to a greater extent for Si plus a single fungicide application, at both Santa Rosa and at Matamoros (Fig. 3.2). At Santa Rosa, reductions of 35 and 67% in AUDPC values below those of the control were observed for Si plus one fungicide application and Si alone, respectively (Fig. 3.2a). Similarly, reductions of 39 and 77% below control values were noted at Matamoros (Fig. 3.2b). At Santa Rosa, no significant differences in neck blight was found between Si alone and untreated plots at either evaluation date (Fig. 3.3). At Matamoros, Si alone reduced neck blight by 48% when compared to the control at the first evaluation date and by 40% at the second (Fig. 3.4). At both locations, nearly all Si plus fungicide treatments significantly reduced neck blight when compared with Si alone or the control for the two evaluations (Figs. 3.3 and 3.4). Exaggravations to those were observed at Santa Rosa, where plots treated with Si plus

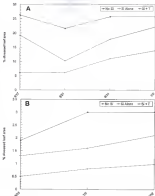


Figure 3.1 Growth progress curves of leaf blade for rice treated with silicon (Si) and orthophosphoric acid at tillering (T) at (A) Santa Rosa and (B) Masantar, Cebu, 1994

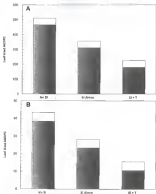


Figure 3.2. Values of total yield for disease progress curves (A) (SDPC) for leaf blight (B) not treated with isolates (B) and with fungicide applied as foliar spray (T) in A) Santa Rosa and B) Miraval, Colombia in 1994. White bars represent LSD values ($P < 0.05$) for comparison of means.

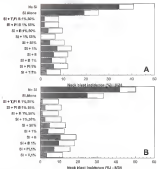


Figure 3.4 Incidence of tick, Mass assessed on A) 24 August and B) 31 August at Marston. Cows in each treatment were treated with ivermectin (1%) plus ivermectin and moxidectin applied at 100% (1%), ivermectin (1%), ivermectin (1%), ivermectin (1%), ivermectin (1%), ivermectin (1%), ivermectin (1%), ivermectin (1%), ivermectin (1%), ivermectin (1%), ivermectin (1%). Ivermectin was applied at 100% and moxidectin was used for ivermectin (1%), ivermectin (1%), and ivermectin (1%). White bars represent LSD values ($P < 0.05$) for comparisons between means.

fungicide applied at heading or tillering and 1% heading did not differ significantly with wheat outside straw plots treated with Se alone or the control (Fig. 3.3). At the first evaluation at Santa Rosa, the treatments presenting all Se and two or five fungicide applications had less neck blast (33-54%) than the other treatments, although single fungicide treatments significantly reduced neck blast by 31-37% when compared to Se alone or the control (Fig. 3.3a). Similar patterns were observed at the second evaluation, where two to five fungicide applications provided disease reductions of 14-54%. Single applications of fungicide reduced neck blast by 5-13% when compared to untreated plots (Fig. 3.3b). As the thermal unit, no significant differences in the incidence of neck blast were observed among any of the Se plus fungicide treatments at the first evaluation, with the exception of Se plus fungicide applied at 1% heading. Neck blast was significantly greater at that treatment than for Se plus fungicide applied at both 1% and 30% heading (Fig. 3.3c). Single fungicide applications reduced neck blast by 79-88% over the control, as compared to disease reductions between 44 and 100% for Se plus multiple applications (Fig. 3.3d). Ranges of neck blast from the second evaluation were similar to those of the first evaluation. Two to five fungicide applications provided 77-88% reductions in disease incidence and single applications reduced incidence by 11-30% (Fig. 3.3d).

Leaf rust. Evaluations of leaf rust were discontinued before the 1% and 30% heading stages. Therefore, fungicide applications made after the last date of evaluation of rust are not included in this analysis of data for leaf rust. Silver plus fungicide generally reduced the severity of leaf rust at both test sites (Fig. 3.3). At Santa Rosa, AUDPC values for leaf rust were not reduced below those for the control by Se alone (3%), however, Se plus fungicide applied at heading only or tillering only reduced the

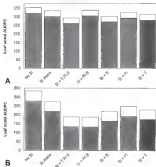


Figure 3-8. Severity of leaf rust, determined by area under the disease progress curve (ALDPPC), on A) Santa Rosa and B) Mineral, Colombia in 2008 from wheat treated with azoxystrobin (T1) plus tebuconazole and fenpropimorph applied at tillering (T2), panicle emergence (T3) and heading (T4), or various combinations thereof. Tebuconazole was applied at tillering and fenpropimorph only, and tridemorph was used for sprays made at heading. Values have been repeated. LSD values ($P < 0.05$) for comparisons between means.

severity of leaf rust by 13.12% over the control and did not differ significantly from β_2 plus three fungicide applications (Fig. 3.3). Plots treated with β_2 plus three fungicide sprays had AUDPC values that were 18% lower than the control. At Matani, β_2 alone significantly reduced yield by 12% over the control. Treatment with β_2 plus single applications of fungicide reduced yield by 31.41% in comparison to the control, and two or more sprays also provided reductions of 32-33% (Fig. 3.3b).

Yield and yield components. Yields of cowpea per ha were not significantly increased by β_2 alone when compared to the untreated control at Forti Kono (Fig. 3.3c). Yields per hectare for plots treated with β_2 plus one fungicide spray were significantly greater (24.6%) than for those of the control plots. Season plus a single application of tricyclazole at heading, 1% heading, or 50% heading provided yield increases that were not significantly different from treatments with β_2 plus two applications of fungicide made at sowing and 1% heading (Fig. 3.3d). Treatment with β_2 plus tricyclazole applied at heading and 1% heading, pre-harvest and 1% heading, or 1% heading and 50% heading significantly increased yields when compared to treatment with β_2 plus single applications of fungicide. Yields were significantly higher (28%) in those plots that received β_2 plus at least applications of fungicide as compared to the control, and were increased between 18% and 112% with three or more applications of fungicide (Fig. 3.3e).

At Matani, yields were significantly higher in both β_2 alone and all β_2 plus fungicide-treated plots (32-33%) when compared to the untreated control (Fig. 3.3d). No differences were observed between yield values of β_2 alone or any β_2 plus fungicide treatment.

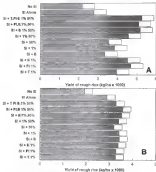


Figure 14. Yields of rough rice (t/ha). **A)** Santa Rosa and **B)** Miraval, Colombia in 1999. Rice plots treated with various nitrogen levels and insecticide applied at tillering (T), panicle initiation (PI), heading (H), 1st + heading (1H) and 50% heading (50H), or various combinations thereof. Insecticide was applied at tillering and heading only, and fungicide was used for groups made at heading, 1st + heading, and 50% heading. White lines represent LSD values ($P < 0.05$) for comparisons between means.

Solomon alone reduced grain distribution at Santa Rosa by 26% over the control. Ratings of grain distribution for *S. oryzae* were not significantly different from any of the silences plus fungicide treatments except *S. oryzae* plus tebuconazole applied at 1% heading ($P < 0.05$) (Fig. 1.7a). Soliman plus single treatments of fungicide reduced grain distribution by 17–43% (depending on the rating) and performed as well as two or more applications (Fig. 1.7a). At Miravalles silences also significantly reduced grain distribution, both with and without fungicides, by 14–36% as compared to the control (Fig. 1.7a). Soliman plus fungicides applied four or five times provided significantly lower grain distribution ratings than *S. oryzae* or any other *S. oryzae* plus fungicide treatment. However, ratings of grain distribution for *S. oryzae* were not significantly different from those for *S. oryzae* plus fungicides applied one or two times, except for the treatment of *S. oryzae* plus fungicide applied at tillering and 1% heading (Fig. 1.7a).

At Santa Rosa, grain fill was positively influenced by *S. oryzae* applied with fungicides. Soliman alone increased the number of filled grains at Santa Rosa by 29% over the control, although the two were not significantly different ($P < 0.05$) (Fig. 1.7a). Grain fill was significantly higher (40–53%) for treatments with *S. oryzae* plus single applications of fungicide applications when compared to the control. Treatments with *S. oryzae* plus one or five applications of fungicide increased the number of filled grains by 34% (Fig. 1.7a). The effects of soliman and soliman plus fungicides on the weight of filled grains at Santa Rosa (Fig. 1.7a) followed the same trends as seen for grain fill (Figure 1.7a), however, a significant increase in the weight of filled grains (an average of 42%) over the control was observed. Generally, no significant differences in the weight of filled grains between plots treated with *S. oryzae* plus one or two fungicide sprays were recorded. Soliman plus four

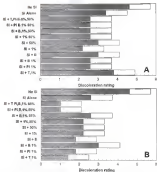


Figure 3.17: Ratings of grass decoloration obtained from the harvest of rice at A) Bahia Grass and B) Muzone in 1994. Plots were treated with sodium (Na) plus methylphenol and insecticide applied at inferring (IT), possible reduction (PT), feeding (BT), 1% feeding (BT1) and 10% feeding (BT10) or various combinations thereof. Methylphenol was applied at inferring and feeding, only, and insecticide was used for spring season at feeding, 1% feeding, and 10% feeding. White bars represent LSD values (F-test) for comparison between means. Scale: 0=clean grass 4=highly decolorated grass

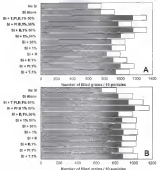


Figure 3.8. The number of filled grains of rice per 10 panicles from **A)** Santa Rosa and **B)** Mitú, Colombia in 1994. Plots were treated with silver (Bt) plus fungicides and insecticides applied at tillering (T), panicle initiation (PT), heading (B), 1% heading (1%), and 20% heading (20%) or various combinations thereof. Fungicides were applied at tillering and heading only, and insecticide was used for sprays made at heading, 1% heading, and 20% heading. White bars represent LSD values ($P < 0.05$) for comparisons between plots.

or five fungicide applications significantly increased the weight of filled grains as compared to 3x plus single fungicide sprays and all but the treatment schedules that included 3x plus two applications of fungicide made at panicle initiation and 1x heading or at 1x heading and 30% heading (Figure 3.3a).

At Milazul, the number of filled grains measured by 17% flower plots treated with 3x alone when compared to the control, and was not significantly different from any of the 3x plus fungicide treatments, regardless of timing, except 3x plus five fungicide applications (Fig. 3.3b). The number of filled grains counted in 3x plus single fungicide applications were not significantly different than counts obtained from 3x plus two, three, or five fungicide applications. Increases of 31-33% over the control (received with 3x plus single applications of fungicide), while two or three applications resulted in increases of 17-18%. Subsoo plus four or five fungicide applications increased filled grains by 14 and 6%, respectively (Fig. 3.3b). Weight of filled grains (Fig. 3.3b) followed nearly identical patterns as for the number of filled grains (Fig. 3.3a). Subsoo alone increased the weight of filled grains by 21% over the control, which was not significantly different from any 3x plus fungicide treatment, regardless of timing, except the treatment with 3x plus four fungicide applications (Fig. 3.3b). Subsoo plus single applications of fungicide increased filled grain weight in levels similar to 3x plus two or five fungicide sprays (23-47%).

Blindness

The application of calcium silicate (polysilicate) in conjunction with routine timed applications of fungicide to different soils in eastern Colombia effectively reduced the incidence and severity of blast and leaf blast. Silicate in combination with fungicides

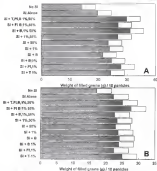


Figure 3-B: The weight of dried grains of soy per 10 panicles from A) Soya Bean and B) Maize, Colombia. Plots were treated with azoxystrobin (IT) plus imidacloprid and triazophos applied at tillering (IT) + panicle initiation (IT) + heading (IT) + 1% loading (1%) and 50% loading (50%) or various combinations thereof. Imidacloprid was applied at tillering and heading only, and triazophos was used for sprays made at heading, 1% loading, and 50% loading. White bars represent mean values of 3.50 (P < 0.05) for comparisons between means.

also reduced grain decomposition, and increased yield and grain quality. The choice of experimental sites provided an opportunity to observe the effects of Si fertilization, in comparison with fungicide applications, on disease and yield losses under conditions of high levels of inoculum (Santa Rosa) and low levels of inoculum (Maracá).

The severity of leaf blight was reduced in both experimental sites by applications of Si , with and without inputs of silicic acid, which confirms previous reports (de Azevedo *et al.* 2003). Si alone provided a significant reduction in the severity of leaf blight in Santa Rosa and Maracá, and the application of a single application of silicic acid further reduced blight severity.

Daveoff *et al.* (14) reported that applications of Si alone could provide control of neck blight as levels not significantly different from fungicides. They suggested that fertilization of rice with Si could be related to reduce or eliminate applications of fungicide required to control neck blight. As the rate of Si applied in the present study, it appears that it is possible to reduce the actual number of spray events in a season and provide a high degree of control of neck blight. Applications of Si alone did not reduce the incidence of neck blight as compared to the control in Santa Rosa. Significant reductions of neck blight were achieved only through the application of fungicides. Treatments with three or more applications of fungicides resulted in the lowest incidence of neck blight, followed by two and then one application of fungicides. Where fewer than five fungicide sprays were applied, timing of fungicide application appeared to affect disease control. Applications made at 7th and 10th leafage were the most effective for decreasing the incidence of neck blight when the number of fungicide applications was reduced. At Maracá, Si alone significantly reduced neck blight incidence (by 40–45%) as compared to

the control. The application of fungicide in combination with Si significantly reduced root blight incidence by 79.100% when compared to the control or Si alone, and no differences were observed among the various fungicide treatments. Generally, Si plus single fungicide sprays applied at heading, T5 heading, or 90% heading provided disease control equal to two or more applications of fungicide. The most probable explanation for the lack of control of root blight observed at Santa Rosa and the reduction in root blight observed at Mineral is the influence of the amount of inoculum present and the rate of application applied. The experimental farm at Santa Rosa represents an area of unusually high disease severity, maintained due to the presence of CIAT in the wheat nursery and breeding program (34). The farm at Mineral was only recently planted to rice and was in an area in which the severity of disease is considerably lower. Fungicide was applied at both rates at 400 kg ha⁻¹ (phenanthrolic) at a rate lower than optimal for disease control (42) in a location such as Santa Rosa but adequate for the environment at Mineral. Increasing the amount of Si applied to rice to 800–1000 kg ha⁻¹ at Santa Rosa would most likely increase disease control to levels seen at Mineral.

Leaf mold was also reduced by applications of Si in combination with fungicide at Santa Rosa and by both Si and Si plus fungicide at Mineral. At Santa Rosa, the reduction in leaf mold by Si alone was not significantly different from the control, and the addition of fungicide only slightly reduced the disease by 13–19%. Silicon plus applications of fungicide made at tillering only or heading only were as effective as Si plus two or more applications of fungicide for the control of leaf mold. At Mineral, Si alone did provide a significant reduction of leaf mold and disease control was not significantly different from Si plus fungicide applied once at tillering; periodic infection,

or burning. Nitrogen plus fungicide applied at silking only, heading only, or at silking, panicle initiation, and heading reduced the severity of leaf rust to the lowest levels.

The differences in the performance of 5s between the two sites can again be related to the higher level of leaf blast observed at Santa Rosa. Evaluations of leaf rust, which began after termination of leaf blast evaluations, were made difficult due to the presence of leaf blast, and a confounding effect from the collection of rice by both pathogenologists may have obscured differences among the treatments.

Yields were increased significantly only at Miraflores, and grain distribution was reduced by 5s alone and with fungicide at both sites, confirming previous reports (43,45,47,134). At Santa Rosa, the effects of 5s combined with fungicides, were consistent with the results seen for neck blast. Nitrogen alone increased yields by approximately 20%, although this was not significantly different from the control. Treatment with 5s plus two applications of fungicide, made at panicle initiation and 1% heading or heading and 1% heading, increased yields as effectively as 5s plus fungicide applied three or four times. Yields for 5s plus fungicide applied at panicle initiation and 1% heading were not significantly different from yields for 5s plus fungicide applied at all timings. Nitrogen plus fungicide applied once (at 1% heading or 50% heading) increased yields to the same level as 5s plus fungicide applied twice (at silking and 1% heading or heading and 1% heading). At Miraflores, no significant differences in yield were observed among 5s alone or 5s plus fungicide applications (regardless of timing), with all treatments increasing yield as compared to the control. Again, differences in the performance of 5s on yields at Santa Rosa and Miraflores can be explained by high levels of blast and the low rate of 5s applied. The rate of 5s used in this study appears to be more

that adequate or increase yield under conditions of low severity of blast, but requires the input of fungicide to be successful when the level of blast is higher. Despite this, the number of applications of fungicide can be reduced without affecting yields at both locations. Indeed, at Minatitlán, it appears to be possible to eliminate fungicide applications entirely and still obtain acceptable yields.

Grain quality was enhanced by applying Zn alone or with fungicide. At both Santa Rosa and Minatitlán, Zn alone or Zn plus single fungicide applications significantly reduced grain discolouration when compared to the control, concerning walk-through reports (43, 132). Blumes in combination with a single application of fungicide resulted in 1% heading at Santa Rosa and at heading at Minatitlán reduced grain discolouration as well as Zn plus two to five applications of fungicide.

Grain fill at Minatitlán and the weight of filled grains at Santa Rosa and Minatitlán were positively influenced by applications of Zn with and without fungicides. This is supported by reports that Zn increases fertility in individual spikelets, thereby increasing grain fill (21). The general trends observed for Zn alone and Zn plus fungicide against neck blast and increases in yield were present with regard to grain fill and filled grain weight. At Santa Rosa, with high levels of inoculum and a low rate of Zn , Zn alone required at least one fungicide application (probably at 1% or 50% heading) to significantly increase grain fill and weight over the control. However, at Minatitlán, Zn alone was sufficient to increase the number of filled grains. Blumes has been reported to improve plant's health by reducing resistance of secondary branches to infection, as well as by strong flushing the hull (14). With indirect damage by *M* grains and other parts on secondary branches and spikelets, disruption on the flow of photoassimilate to

developing grains are lowered and may help to explain the higher number of filled grains and the increased weight of filled grains sometimes observed where *Da* has been applied.

Selenia can be used successfully in conjunction with fungicides to manage blight and mild, and to help improve yield and yield quality. Depending upon the level of severity of disease, it appears that the number of fungicide sprays can be reduced from five to one or two. This might be considered altogether as areas of high-disease severity by increasing the use of *Da* used to date has such. The implications of this finding are important for rice growing regions such as Calicut's, where five to five applications are used by commercial growers to control blast (*P. Oryzae*, *perusal* recommended). Limiting applications of fungicide will have a significant economical and environmental impact in not only Calicut, but other rice growing areas where fungicides are currently being used to control diseases such as blight and leaf mild.

CHAPTER IV
EFFECTS OF CALCIUM SILICATE FERTILIZER AND FUNGICIDES AS FULL
AND BRIDGEHEADS ON THE INCIDENCE AND EXTENT OF BLAST IN
UPLAND RICE

Introduction

Rice blast, caused by *Magnaporthe oryzae* (Hobart) Sacc. (synonym *Pynodora oryzae* [Cooke] Sacc.), is one of the most destructive diseases of rice (*Oryza sativa* L.) and is a serious constraint to production in most of the world's rice-growing regions [1]. The disease occurs in two main forms, leaf blast and neck blast [11,12]. While the latter form of rice blast is the most damaging in terms of lost yield, leaf blast can be quite serious and can result in heavy crop damage or loss before plants reach the reproductive phase of growth [13,115]. Blast is especially problematic in temperate areas, and in tropical uplands, such as those found in West Africa and the mountains of South America [11,15,115]. Although upland rice accounts for only about 10% [15 million hectares] of the total area planted to rice worldwide, it comprises the majority of rice cultivated in parts of Asia, Africa, and South America [24].

Leaf blast can be managed by varying the time of planting, avoiding excessive inputs of nitrogen, maintaining high levels of soil moisture, planting blast-resistant cultivars, and using fungicides [11,14,107]. The use of fungicides provides good control of the disease, but the high cost of materials and application makes them an uneconomical option for many of the world's rice growers [98]. Disease resistance has been achieved through the planting of resistant varieties, however, their effectiveness has proved to be

short-lived in the field because of the appearance of new pathogenic races of *M. grisea* (34). Magnaporthe grisea exhibits a great degree of variability and adaptability in nature, and its ability to generate new pathogenic races are affected by deployed resistance genes. In another study, resistant cultivars suffered over periods 1-2 years (2).

A promising alternative control for rice blast is the application of silicon (35). Silicon is an essential nutrient for rice. The rice plant has been shown to accumulate large quantities of Si from soil (33-36) and deficiencies of the element have been correlated with increased incidence of diseases such as blast, and brown spot, caused by *Oryzohelminthium sapientum* (36 & Kumbayada et al) Drieda. Si Datura (37,38,116,118). Certain soil types such as laterites (greater than 80% organic matter), Chernoz, and Ultisols, have been identified as Si deficient due to high organic matter content (3), in the case of the latter two types, high degrees of weathering, leaching, and acidity (37,118,193). The predominant soil types in the upland rice-growing areas of Latin America are Chernoz and Ultisols (37,153).

Several researchers have shown that treatments of Si-deficient soils with silicon silicate fertilizers can reduce incidence and severity of diseases such as brown spot and rice blast (33,35,43,45,46,116,120-124). In one study, Dattaraj and Sengupta (34) found that Si alone reduced the incidence of rice blast by over 50% when compared to an untreated control, and that this effect was not significantly different from the reduction provided by the application of fungicide. In the same study, Si in combination with fungicide reduced the incidence of rice blast by over 80%. In recent research, conducted on Si deficient soils in eastern Colombia, Si was used with fungicide to reduce the number of fungicide applications necessary to control rice blast (125).

Degate is potential as a management tool for rice blast, little is known about the actual mechanisms behind the observed resistance to disease, effects on the epidemiology of rice blast, or the feasibility of combining it and fungicides to manage blast (40,47,49,57). Fly (38) determined that fungicides could be applied at reduced rates in nonplanted beds of ricegrass in *Pyricularia* epidemics in culture on rice plants. Because of the ability of *Py* to enhance resistance to blast at the seed plant, studies were initiated to investigate the effects of *Py* alone and with foliar and reduced rates of commonly used fungicides on disease progress (seed blast), incidence of seed blast, and yields in an optimal rice association with high annual levels of degate severity. Results were analyzed to determine if *Py* could be used to eliminate or reduce the rate of fungicide needed to control rice blast. Additional studies were conducted to determine the efficacy of a single *Py* application over a 2 year period.

Materials and Methods

Location. Experiments were conducted in 1983 and 1984 at two different sites located approximately 30 km east of Villavieja, Colombia, in the "Bosque" (forest) region. Locations were chosen because of the extremely high level of rice blast present (34) and was in the Santa Rosa research station maintained by the Centro Internacional de Agricultura Tropical (CIAT) as a rice breeding site and rice blast nursery. The soil type was an Ocrepseud with a pH of 4.7 and approximately 4 ppm plant available N_2 (as determined by the CIAT soil testing laboratory). The experimental area located approximately 2 km east of Santa Rosa at the Instituto Colombiano de Agricultura's (ICA) La Libertad experimental station. The soil type (Ocrep) at the La Libertad site was

representative of upland conditions in the Americas of Colombia. Soil pH was 4.7 and less than 1 ppm plant-available sodium was determined to be present.

Soil preparation and planting. Dolomitic limestone (CaCO_3/Mg) was incorporated into the soil approximately 30 days prior to planting at both locations. At Santa Rosa, phosphate, potassium, magnesium sulfate, and boron were preplant incorporated at rates of 60, 30, 60, and 5 kg ha⁻¹, respectively. Phosphate (100 kg ha⁻¹), potassium (90 kg ha⁻¹), and zinc sulfate (24 kg ha⁻¹) were preplant incorporated into each plot at La Libertad. Before, in the form of wettable sulfur (CaSO_4) (R.T. Vandelbik, Newark CT), was broadcast by hand at rates of 0 and 1400 kg ha⁻¹ and incorporated approximately 3 days before planting by disking. Plots that did not receive S were treated with agricultural lime (CaCO_3) to raise the level of Ca to that of plots treated with calcium sulfate. The first susceptible non-cultivar 'Oryza 1' was still needed at Santa Rosa as a variety of 1 cm under new spacing of 0.35 m. A first susceptible cultivar with characteristics better suited for warmer soils, 'Loma 1' was planted at La Libertad. The seeding rate was 60 kg ha⁻¹ at both locations. Planting dates at Santa Rosa were 12 May in 1995 and 13 May in 1996, and at La Libertad planting was done on 18 May in 1995 and 1996. Methodologies and seeding rates were identical in both years of the study.

Experimental design and plot layout. At Santa Rosa and La Libertad, the tests were randomized-complete block designs arranged as 2×4 factorials with five replicates. Each plot was 5 × 4 m. The main effects were calcium sulfate (0) at 0 and 1000 kg ha⁻¹ and nitrogen at 0, 100, 150, and 200 kg ha⁻¹, or mycorrhizae at 0, 30, 75,

and 300 g ha⁻¹, providing a total of eight treatments per block (Table 4.2). These rates were 0, 10%, 25%, and 100% of the recommended rate of each fungicide. Dethloff et al. (43) identified 57 ha⁻² malicium, alium, which provides 1000 kg of elemental S ha⁻¹, as the rate providing maximal response in relation to the amount of material applied. Each plot was subdivided into two 5 × 4-m sections to allow for the study of the efficacy of a single application of malicium for residual activity in the following year. In 1999, S was applied as described in the previous section to one half of each plot and the remaining half was left untreated until 1998. In 1998, the portion of each plot that did not receive malicium in 1999 was amended and the portion that received malicium in 1999 was left amended. For the purposes of analysis, the residual experiment was treated as a split-plot design with five replicates. Whole plots were fungicide rate (0, 10%, 25%, or 100% of the recommended rate of azoxystrobin or triazophos) and sub-plots corresponded to the year of malicium application (1999 or 1998). In Colombia, it is common for rice growers to apply azoxystrobin (Skorum 300 SC, Bayle AG) to control leaf blast because of the lower cost of that fungicide, and to apply triazophos (Ekon 75 WP, Orellana) known to be more effective than azoxystrobin, to control of neck blast (De Frenedo-Correa, personal communication). To approximate standard grower practices, azoxystrobin was applied approximately 20 and 30 days after seeding (2342) for control of leaf blast (Table 4.2), and triazophos was applied at heading, 15% panicle emergence, and 50% panicle emergence. Fungicides were applied in 230 L of water ha⁻¹ using a manually pressurized backpack sprayer. At both locations, nitrogen was applied at 75, 90, 90, and 75 kg/ha at rates of 15, 10, 20, and 40 kg ha⁻² respectively. The Santa Rosa site received an additional 30 kg of phosphorus ha⁻¹ at 30 DAE, while 45 kg of

Table 4.1 Treatments for rice with infestations of *Scaphisoma* combinations at Santa Rosa and La Libertad in 1995 and 1996

| Rate (g ha ⁻¹) | Proportion of infested rice of <i>Scaphisoma</i> ^a |
|----------------------------|---|
| 0 | 0 |
| 1000 | 0 |
| 0 | 0.10 |
| 1000 | 0.10 |
| 0 | 0.20 |
| 1000 | 0.20 |
| 0 | 1.0 |
| 1000 | 1.0 |

^aInfestations applied at 0, 100, 150, and 1000 of ha⁻¹. *Thelysianus* is applied at 0, 30, 15, and 100 g ha⁻¹.

Table 4.2 Dates of application of infestations to rice at Santa Rosa and La Libertad in 1995 and 1996

| Santa Rosa | | La Libertad | |
|------------|---------|-------------|---------|
| 1995 | 1996 | 1995 | 1996 |
| 7 June | 6 June | 6 June | 6 June |
| 25 June | 20 June | 23 June | 23 June |

potassium kg^{-1} and 23 kg of magnesium sulfate kg^{-1} were applied at 30 DAF in La Libertad.

Fungicide (Bayer AG, IPRO) and bactericide (Bayer AG, BADA AG, BADA) were applied at their recommended rates for control of weeds, and the insecticides deltamethrin (Deltin, Sumitomo IRI) and chlorpyrifos (Lorsban, Dow Chemical) were applied as needed for insect control.

Disease collection and analysis. In 1999 and 1998, prior to the application of disease, eight score tubes located at the center 8 m² of each plot were tagged with a 2-mm section of rubber tubing that had been coated with Saccharose paste. At each location, leaf area was evaluated throughout the epidemic by estimating the proportion of leaf area with disease on each leaf of the marked score tubes. Evaluation dates for both locations are listed in Table 4.3.

Data were used to construct disease progress curves for each treatment. The efficacy of each treatment was determined by calculating the area beneath individual disease progress curves (AUDPC) using the following formula:

$$\text{AUDPC} = \sum_{i=1}^{n-1} \left(\frac{y_i + y_{i+1}}{2} \right) (t_{i+1} - t_i)$$

where y_i = disease proportion at the i^{th} observation and t_i = time (in days), and n = total number of observations (13). The values obtained were then analyzed with the analysis of variance procedure (ANOVA) and regression (SAS, Cary NC).

Disease progress curves were transformed using the Gompertz transformation (Beyer, 1972) to obtain a non-parametric k , referred to hereafter as k_{G} , corresponding to the apparent infection rate / final diseasability rate (de Plank (147). The rate k_{G} is

Table 4.3 Evaluation dates for field trial of rice at Santa Rosa and La Libertad (1990-1992). The actual evaluation date and the day relative to the start of evaluation (day 0) are listed.

| Santa Rosa | | | | La Libertad | | | |
|------------|-----|---------|-----|-------------|-----|---------|-----|
| 1990 | | 1991 | | 1991 | | 1992 | |
| Date | Day | Date | Day | Date | Day | Date | Day |
| 1 June | 0 | 4 June | 0 | 3 June | 0 | 10 June | 0 |
| 8 June | 7 | 11 June | 7 | 10 June | 7 | 17 June | 7 |
| 15 June | 14 | 18 June | 14 | 17 June | 14 | 24 June | 14 |
| 22 June | 21 | 25 June | 21 | 24 June | 21 | 29 June | 21 |
| 29 June | 28 | 3 July | 28 | 29 June | 28 | 3 July | 28 |
| 27 June | 26 | 3 July | 30 | 28 June | 26 | 11 July | 31 |
| 26 June | 25 | 11 July | 38 | 4 July | 34 | | |
| 3 July | 34 | 22 July | 46 | | | | |
| 11 July | 40 | | | | | | |

parameter was calculated by transforming values of disease proportion (y_t) at each observation date with the following equation (3.3)

$$\text{gompit}(y_t) = \ln[-\ln(y_t)]$$

Following transformation, $\text{gompit}(y_t)$ values were plotted against time ($\ln(\text{days})$) and linear regression was used to calculate a slope, equivalent to $\ln(a_0)$ parameter, for each leaf. Values of rate and disease proportion on the final day of evaluation were collected for each treatment and analysed by ANOVA and regression where appropriate.

Incidence of leaf blight was estimated by evaluating 30 randomly selected panicles per plot at approximately 3 weeks post-flowering. Incidence was recorded on panicles with a rating of 5, 3, or 0, based upon a 0-5 scale. The scale, developed by the International Rice Research Institute (IRRI) is as follows: 0=no symptoms, 1=lesions on panicle and branches, 3=lesions on branches and panicle area, 3=lesions partially surrounding base of panicle, 5=lesions completely surrounding base of panicle, with greater than 30% of grains filled, and 4=lesions completely surrounding base of panicle, with fewer than 30% of grains filled (74). Plots were harvested by hand at both harvests. A 3 × 3 m section was marked in each subplot using a wire frame, and only those tillers within the frame were cut. Though not possible for $\frac{1}{3}$ was estimated from grain harvested in the 6 m² portion of each sub plot and was adjusted to reflect a 10% moisture content.

Samples of leaf tissue were collected within 24 hours of each evaluation of leaf blight on tiller (fresh leaves) to determine if concentrations of plants in exposed tiller and 30-exposed plants at the time of assessment of disease. Additionally, roughly 500 g of stem and leaf tissue were collected and dried at harvest time to measure concentration of

to six plants in uninfested and six uninfested plots for evaluation with mean plant incidence and severity) and yield. In 1993, tissue was collected at the end of the latest epidemic and at harvest. Dead tissue was ground to a fine powder using a Wiley mill. Tissue content of tissue samples was determined by first digesting 0.1 g of dead tissue as described by Ellis and Boyler (48), followed by automated colorimetric analysis. Data obtained were analyzed by ANOVA and regression when appropriate.

Results

Effects of Colletotrichum Blight and Eutraphion on Disease Progress

Colletotrichum blight, as nearly all cases, significantly reduced overall disease progress, as determined by apparent infection rate, and the severity of blight at the last evaluation date (final disease) in Santa Rosa and La Libertad in both years. Depending upon observational year of the study, increasing rates of eutraphion also reduced infection rate and final disease.

Santa Rosa 1993. Blights applied at 0 and 1000 kg ha⁻¹, combined with eutraphion at 0, 100, 250, and 1000 ml ha⁻¹, showed the progress of leaf blight over a 60-day period in 1993 at Santa Rosa (Fig. 4-1). Disease progress curves were measured with the Gompertz transformation, $\log_e [(1 - \text{inf}) / (1 - \text{inf}_0)]$ by transforming values for proportion of leaf area with disease for each evaluation date to determine apparent infection rate, a measure of the daily rate of disease progress. In all cases, applications of the Gompertz equation resulted in significant linear models ($P < 0.05$) with high correlation coefficients ($R^2 \geq 0.74$) (data not shown) and were judged a suitable model to simulate limited disease progress curves in this study. For each rate of eutraphion, 0 or 1000 kg ha⁻¹ reduced the r_0 of leaf blight by 1.9-12% as compared to 0 or

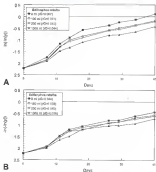


Figure 4.1. Progress of leaflet of rice as the cultivar "Oryza 1" at Santa Rosa, Colombia in 1983. **A.** Gompertz-transformed disease progress curves for four rates of infection, applied to plots not amended with straw (2t). **B.** Gompertz-transformed disease progress curves for four rates of infection, applied to plots amended with 3000 kg of S肥. Each point is the mean of five replicates. $\text{logit}(\text{percentage infection}) = \text{log}(\text{proportion of leaf with symptoms of blast per day})$ obtained by linear regression of each transformed curve.

8 kg ha^{-1} ($P < 0.05$) (Table 4.3). The rate of infection was greatest for the untreated control ($x_0 = 0.073$), and was lowest for the $3000 \text{ kg of Zn ha}^{-1}$ plus $1000 \text{ ml of silicophen ha}^{-1}$ ($x_0 = 0.034$). There was no difference in x_0 between the 1000 ml ha^{-1} rate of silicophen without Zn and $3000 \text{ kg of Zn ha}^{-1}$ without silicophen ($P < 0.05$). Significant cubic relationships ($P < 0.001$) were found between x_0 and rate of silicophen applied with and without Zn at 3000 kg ha^{-1} (Fig. 4.2a). When the rates of silicophen were increased from 0 to 3000 ml ha^{-1} , x_0 was reduced by 13% without Zn and by 38% with Zn.

Infection observed in combination with silicophen reduced the severity of leaf blight at the final evaluation date (x_{max}) in 1995 (Fig. 4.2a). At each rate of silicophen, x_{max} was reduced from 43–48% by $1000 \text{ kg of Zn ha}^{-1}$ as compared to 8 kg ha^{-1} ($P < 0.05$) (Table 4.4). Final disease was significantly higher for the untreated control than for any of the other Zn-silicophen combinations ($P < 0.05$). Silicophen at 1000 ml ha^{-1} reduced x_{max} by 48% as compared to the untreated control, as did $3000 \text{ kg of Zn ha}^{-1}$ (an silicophen); means did not differ significantly between these treatments ($P < 0.05$). Zn plus silicophen at 1000 ml ha^{-1} reduced x_{max} by 48% as compared to the untreated control ($P < 0.05$) (Table 4.4). For plots treated with 0 and $3000 \text{ kg of Zn ha}^{-1}$, significant cubic relationships were found between x_{max} and rate of silicophen for each rate of Zn ($P < 0.001$), indicating a significant difference among rates of silicophen for x_{max} . Increases in silicophen rate from 0 to 3000 ml ha^{-1} decreased x_{max} by 47% without Zn, and decreased x_{max} by 38% when applied to plots treated with $3000 \text{ kg of Zn ha}^{-1}$ ($P < 0.05$) (Fig. 4.2a).

Santa Rosa 1996 The effects of Zn and silicophen on the progress of leaf blight over a 40-day period in 1996 at Santa Rosa are shown in Fig. 4.4. In general, the rate of

Table 4.4 Mean comparisons of apparent infection rate (r_a), percent damaged leaf area at the final evaluation of leaf/blast (r_{leaf}), and area under the disease progress curve (AUDPC) of leaf/blast for eight isolates (Ss) plus multi-strain mixture/own application (M) at Santa Rosa on 1994

| Is | Etiologyless | | r_a^a | r_{leaf}^b | AUDPC |
|------|---------------------|---------------------|----------------------|---------------------|---------|
| | kg ha ⁻¹ | ml ha ⁻¹ | | | |
| 0 | 0 | 0 | 0.037 a ^c | 41 a | 6.74 a |
| 0 | 0 | 100 | 0.051 b | 30 b | 4.76 b |
| 0 | 0 | 250 | 0.049 b | 29 b | 4.48 b |
| 0 | 0 | 1000 | 0.048 b | 22 c | 3.96 c |
| 1000 | 0 | 0 | 0.044 cd | 21 c | 3.05 c |
| 1000 | 0 | 100 | 0.039 cd | 16 d | 2.30 cd |
| 1000 | 0 | 250 | 0.040 cd | 13 cd | 2.05 c |
| 1000 | 0 | 1000 | 0.035 d | 13 d | 1.05 d |

^a r_a =daily rate of progress of leaf/blast (change in the proportion of leaf area with symptoms per day)

^b r_{leaf} =percentage of leaf area with symptoms of rice blast at the final evaluation date

^cComparisons of any two values in the same column followed by the same letter do not differ significantly ($P=0.05$) as determined by t tests on transformed means. Each value is the mean of five replications.

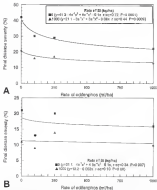


Figure 4.3 Relationship between the percentage of diseased leaf area at the final evaluation of leaf blast of rice and rate of nitrogen applied to 36-atomized and non-atomized plots of Santa Rosa, Colombia in A) 1993 and B) 1996. Each point is the mean of five replications.

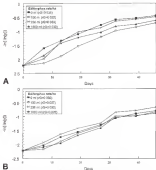


Figure 4.4: Progress of leaf blight on coffee (the cultivar 'Coffea F' in Santa Rosa, Colombia in 1994). A: Gompertz transformed disease progress curves for four rates of infection, applied to plots not associated with *S. kr* (50). B: Gompertz transformed disease progress curves for four rates of infection, applied to plots associated with 1000 kg of *S. kr*. Each point is the mean of five replicates. Gompertz infection rate (change in proportion of leaf with symptoms of blight per day) obtained by linear regression of each transformed curve.

drainage progress was lower in 1996 than in the previous year. Sulfate at 1000 kg ha^{-1} reduced τ_d of leaf litter by 34, 14, and 12% for the 0, 100, and 1000 ml ha^{-1} rates of nitrophos when compared to the same rates of nitrophos without S. ($P < 0.05$) (Table 4.2). The highest τ_d was found for 0 ml ha^{-1} nitrophos without S. Sulfate at 1000 kg ha^{-1} , without nitrophos, and nitrophos at 1000 ml ha^{-1} , without S, reduced τ_d by 17% and 11%, respectively, when compared to the untreated control ($P < 0.05$) (Table 4.2). Values of τ_d for 1000 kg of S ha^{-1} and for 1000 ml of nitrophos ha^{-1} did not differ significantly ($P > 0.05$). The rate of collection decreased as a linear function as the rate of nitrophos was increased from 0 to 1000 ml ha^{-1} with and without S (Fig. 4.2b).

Sulfate at 1000 kg ha^{-1} reduced the amount of leaf litter present at the end of the exclusion period (γ_{end}) in 1996 at Santa Rosa ($P < 0.05$) (Fig. 4.3a). Total drainage was approximately 30% lower in control plots in 1996 than in 1993 at Santa Rosa ($P < 0.05$) (Tables 4.4 and 4.5). S. reduced γ_{end} by 24–30% as compared to no S at each rate of nitrophos (Table 4.5). Highest values of γ_{end} were found for 0 or 100 ml ha^{-1} nitrophos without S. Nitrophos at 1000 ml ha^{-1} plus 1000 kg of S ha^{-1} reduced final drainage by 43% as compared to the untreated control. S. lower at 1000 kg ha^{-1} reduced final drainage by 46% as compared to the control and by 34% as compared to the highest rate of nitrophos ($P < 0.05$) (Table 4.5). The impact of increased rates of nitrophos on γ_{end} , when applied with 1000 kg of S ha^{-1} , was of a smaller magnitude than that of nitrophos applied without S (Fig. 4.3b). The application of nitrophos at 100, 250, and 1000 ml ha^{-1} , for plots not treated with S, reduced γ_{end} as compared to 0 ml ha^{-1} nitrophos, however, no significant linear relationship ($P > 0.05$) was found between γ_{end} and rate of nitrophos in plots treated with 1000 kg of S ha^{-1} (Fig. 4.3b).

Table 4.5: Mean components of apparent infection rate (λ_a), percent diseased leaf area at the final evaluation of leaf blight (γ_{final}) and area under the disease progress curve (AUDPC) of leaf blight for eight wheat (Bt) plus subpopulation combinations applied to rice at Santa Rosa in 1998.

| Bt | Subpopulation | | λ_a^1 | γ_{final}^2 | AUDPC |
|------|---------------------|----------------------|---------------|---------------------------|-------|
| | kg ha ⁻¹ | ml ha ⁻¹ | | | |
| 0 | 0 | 0.000 a ³ | 21 a | 4.38 a | |
| 0 | 100 | 0.000 bc | 23-bcd | 1.90 cd | |
| 0 | 250 | 0.000 bc | 20-a | 2.50 bc | |
| 0 | 1000 | 0.000 bc | 16-b | 3.70 bc | |
| 1000 | 0 | 0.000 bcd | 11-cde | 1.59 cd | |
| 1000 | 500 | 0.002-d | 9-d | 1.43 d | |
| 1000 | 250 | 0.000 bc | 14-bc | 2.20 bc | |
| 1000 | 1000 | 0.002-cd | 11-de | 1.58 d | |

¹ λ_a =daily rate of progress of leaf blight (change in the proportion of leaf area with symptoms per day)

² γ_{final} =percentage of leaf area with symptoms of rice blight at the final evaluation date.

³Comparisons of any two values in the same column followed by the same letter do not differ significantly ($P < 0.01$) as determined by t-tests on least-squares means. Each value is the mean of three replications.

La Libertad 1998 Selenium application (0 and 1000 kg ha⁻¹ in combination with etidifluthiazol 0, 100, 250, and 1000 ml ha⁻¹ showed the progress of leaf blight over a 31-day period in 1998 at La Libertad (Fig. 4.5). Se at 1000 kg ha⁻¹ reduced mean γ_2 of rice blast by 31, 52, and 26%, respectively for 0, 100 and 1000 ml of etidifluthiazol ha⁻¹, as compared to the same rates of etidifluthiazol without Se ($P < 0.05$) (Table 4.6). When γ_2 was lower for Se at 1000 kg ha⁻¹ without etidifluthiazol when compared to etidifluthiazol applied at 1000 ml ha⁻¹ without Se ($P < 0.05$). The relationship between γ_2 and rate of etidifluthiazol was significant in plots that were not amended with Se, and a 3% reduction in γ_2 was observed as the rate of etidifluthiazol was increased from 0 to 1000 ml ha⁻¹ ($P < 0.001$) (Fig. 4.6a). No significant differences in γ_2 were found between any rate of etidifluthiazol in plots amended with 1000 kg of Se ha⁻¹ without etidifluthiazol.

Final disease at La Libertad was reduced by Se (Fig. 4.7a). Se at 1000 kg ha⁻¹ reduced γ_{final} by 47, 45, and 26% for the 0, 100 and 1000 ml ha⁻¹ rates of etidifluthiazol, respectively, when compared to the same rates of etidifluthiazol without Se ($P < 0.001$) (Table 4.6). The relationship between γ_{final} and rate of etidifluthiazol was significant and significant for plots not amended with Se, and γ_{final} was reduced by 33% as the rate of etidifluthiazol was increased to 1000 ml ha⁻¹ (Fig. 4.7a). Etidifluthiazol, any rate, did not significantly reduce γ_{final} in plots that received 1000 kg ha⁻¹ Se ($P < 0.05$).

La Libertad 1994 Selenium alone and in combination with etidifluthiazol showed the progress of leaf blight over a 31-day period in La Libertad in 1994 (Fig. 4.8). At each rate of etidifluthiazol, Se at 1000 kg ha⁻¹ significantly reduced γ_2 by 31–34% as compared to 0 kg of Se ha⁻¹ (Table 4.7). Treatment with Se at 1000 kg ha⁻¹ reduced γ_2 by 30% as compared to the untreated control and by 33% as compared to the full (1000 ml ha⁻¹) rate of

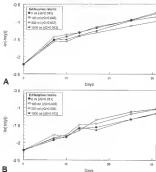


Figure 5.5 Progress of leaf-plots at rice on the volunteer 'Luzon 1' at La Libertad, Colombia in 1991. **A** Composite transformed disease progress curves for four rates of volatiles, applied to plots not weeded with riceon (R0). **B** Composite transformed disease progress-curves for four rates of volatiles, applied to plots weeded with 1000 kg of Bt for 1 ha^{-1} . Each point is the mean of five replications. aD -apparent infection rate obtained by linear regression of \log_2 transformed curve.

Table 4.4 Mean comparisons of apparent infection rate (ρ_{app}), percent diseased leaf area at the final evaluation of leaf blight (ρ_{final}), leaf area under the disease progress curve (AUDPC) of leaf blight for eight wheat (8a) plus entomopathogenic combinations applied to rice at La Libertad in 2006

| 8a | Entomophages | ρ_{app}^1 | ρ_{final}^2 | AUDPC |
|---------------------|---------------------|----------------------|------------------|----------|
| kg ha ⁻¹ | ml ha ⁻¹ | | | |
| 0 | 0 | 0.043 a ³ | 17 a | 1.31 a |
| 0 | 100 | 0.043 a | 11 a | 1.32 a |
| 0 | 200 | 0.031 b | 7 bc | 0.79 bc |
| 0 | 1000 | 0.043 a | 8 ab | 1.09 ab |
| 1000 | 0 | 0.031 b | 4 d | 0.37 ab |
| 1000 | 100 | 0.035 bc | 6 cd | 0.34 abc |
| 1000 | 200 | 0.026 bc | 6 cd | 0.47 cd |
| 1000 | 1000 | 0.035 cd | 4 cd | 0.35 c |

¹ ρ_{app} relatively rate of progress of leaf blight (change in the proportion of leaf area with symptoms per day)

² ρ_{final} percentage of leaf area with symptoms of leaf blight at the final evaluation date

³Comparisons of any two values in the same column followed by the same letter do not differ significantly ($P=0.05$) as determined by t-test on transformed means. Each value is the mean of five replicates

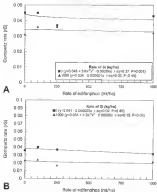


Figure 4.6 Relationship between apparent infection rate (r_C), the change in proportion of leaf with symptoms per day, of leaf that of rate and rate of defoliation, applied to *B. dothidea* and non-susceptible plants in La Estrella, Colombia in A) 1993 and B) 1994. Each point is the mean of five replicates.

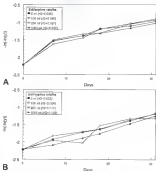


Figure 4.8 Progress of leaf mass at root in the rubber 'Lancet 2' of La Libertad, Colombia in 1994. **A** Gompertz-transformed disease progress curves for four tests of edilaphox, applied to plots not amended with nitroon (50). **B** Gompertz-transformed disease progress curves for four tests of edilaphox, applied to plots amended with 1000 kg of 20-20-20. Each point is the mean of three replicates. \log_{10} -transformed selection rate (change in proportion of leaf with symptoms of blot per day) obtained by linear regression of each transformed curve.

Table 4-7. Mean comparisons of apparent infection rate (r_a), percent diseased leaf area at the final evaluation of leaf blight (y_{final}) and area under the disease progress curve (AUDPC) of leaf blight for eight well-timed-sideline plots containing one subplot in rows at La F. derived in 1995

| SI | | Edinburgh | | |
|---------------------|------------------------------|------------------------------|----------------------|----------------|
| kg ha^{-1} | $\text{m}^2 \text{ ha}^{-1}$ | r_a^1 | y_{final}^2 | AUDPC |
| 0 | 0 | 0.036- <i>a</i> ³ | 7.3- <i>a</i> | 0.06- <i>a</i> |
| 0 | 100 | 0.040- <i>a</i> | 8.4- <i>a</i> | 0.04- <i>a</i> |
| 0 | 250 | 0.037- <i>a</i> | 7.7- <i>a</i> | 0.04- <i>a</i> |
| 0 | 1000 | 0.032- <i>ab</i> | 6.3- <i>ab</i> | 0.06- <i>a</i> |
| 1000 | 0 | 0.023- <i>a</i> | 3.9- <i>bc</i> | 0.20- <i>b</i> |
| 1000 | 100 | 0.024- <i>bc</i> | 3.8- <i>bc</i> | 0.20- <i>b</i> |
| 1000 | 250 | 0.017- <i>a</i> | 3.4- <i>a</i> | 0.20- <i>b</i> |
| 1000 | 1000 | 0.022- <i>a</i> | 2.8- <i>c</i> | 0.20- <i>b</i> |

¹ r_a =daily rate of progress of leaf blight change in the proportion of leaf area with symptoms (per day)

² y_{final} =percentage of leaf area with symptoms of rust blight at the final evaluation date.

³Comparisons of any two values in the same column followed by the same letter do not differ significantly ($P=0.05$) as determined by t tests on least-squares means. Each value is the mean of five replications.

nitrogen ($P=0.05$) (Table 4.7). The relationship between τ_{max} and rate of nitrophos was not significant in plots treated with 0 or 1800 kg ha^{-1} Ss, indicating no change in the apparent infection rate as the rate of fungicide was increased (Fig. 4.6b).

Salvage values (γ_{max}) at La Libertad in 1999 (Table 4.7). At each rate of nitrophos, γ_{max} was lower by more than 40% for 1000 kg of Ss ha^{-1} as compared to 0 kg ha^{-1} ($P=0.05$) (Table 4.7). Salvage at 1800 kg ha^{-1} without nitrophos reduced final disease by 40% as compared to the untreated-control as well by 30% as compared to the full rate (1000 ml ha^{-1}) of nitrophos without Ss ($P=0.05$) (Table 4.7). Mean values of γ_{max} were not significantly reduced by increased rates of nitrophos in plots treated with 0 or 1000 kg of Ss ha^{-1} ($P>0.05$) as determined by linear regressions (Fig. 4.7a).

Effects of 60 Plus Nitrophos on Season-long Severity of Leaf Blight

The application of Ss as the protectant or eradicant of fungicides, reduced the season-long severity of leaf blight at Santa Rosa and La Libertad in eastern Colombia in both years of the study (Figs. 4.5-4.10).

Santa Rosa 1999. Ss at 1800 kg ha^{-1} reduced the area under disease progress curve (AUDPC) for leaf blight, a measure of season-long severity of disease, at each rate of nitrophos by up to 50% as compared to the same rates of fungicide at 0 kg of Ss ha^{-1} ($P=0.04$) (Table 4.4). Nitrophos at 1000 ml ha^{-1} , without Ss, reduced AUDPC by 60% when compared to the control ($P=0.05$). Values of AUDPC were not significantly different between nitrophos at 3000 ml ha^{-1} , without Ss and 1800 kg of Ss ha^{-1} without nitrophos ($P=0.05$) (Table 4.4). The relationship between rate of nitrophos and AUDPC was determined to be significant and cubic (Fig. 4.8a), which was indicative of significant differences among the four rates of nitrophos ($P=0.0001$). For plots not

attended with Si. AUDPC decreased by 34% as the rate of silicic acid increased from 0 to 1000 ml ha^{-1} , and by 46% for plots amended with 1000 kg of Si ha^{-1} (Fig. 4.9a).

Santa Rosa 1996 Severity of blast was lower in 1996 than in 1995 at Santa Rosa. Treatment with Si at 1000 kg ha^{-1} lowered AUDPC's for 0 and 1000 ml ha^{-1} silicic acid, as compared to the same rates of fungicide without Si ($P < 0.05$) (Table 4.3). Highest severity of disease, as determined by AUDPC, occurred where neither Si nor silicic acid had been applied (Table 4.3). Silicon alone reduced AUDPC by 65% as compared to the untreated control, and by 41% as compared to the fungicide only control ($P < 0.05$). A significant, decreasing linear relationship between AUDPC and rate of silicic acid was determined for plots amended with 0 kg of Si ha^{-1} ($P < 0.001$), and a significant cubic relationship was found between AUDPC and rate of silicic acid for plots treated with 1000 kg of Si ha^{-1} ($P < 0.001$) (Fig. 4.9b). The AUDPC of leaf blast decreased as the rate of fungicide was increased with and without the amendment of Si.

La Libertad 1997 The overall severity of leaf blast was considerably lower at La Libertad than at Santa Rosa. Mean AUDPC values for leaf blast at 0 kg of Si ha^{-1} were higher than for 1000 kg of Si ha^{-1} at each rate of silicic acid except 250 ml ha^{-1} ($P < 0.05$) (Table 4.4). Silicon at 1000 kg ha^{-1} , without silicic acid, reduced AUDPC by 72% over the untreated control (Table 4.4). Silicic acid 1000 ml ha^{-1} , without Si did not significantly reduce AUDPC over the untreated control. Silicon at 500 kg ha^{-1} reduced AUDPC by 54% as compared to 1000 $\text{ml of silicic acid ha}^{-1}$ without Si ($P < 0.05$) (Table 4.4). The relationship between fungicide rate and AUDPC of leaf blast was not significant at either 0 or 1000 kg of Si ha^{-1} (Fig. 4.10a).

La Libertad 1996 Severity of leaf blight, as measured by AUDPC, was reduced by Zn at 1000 kg ha^{-1} by an average of 69% when compared to $0 \text{ kg of Zn ha}^{-1}$, regardless of the rate of sulphur (Fig. 4.7) (Table 4.7). Sulfur at 1000 kg ha^{-1} , without sulphur, reduced (Fig. 4.8) AUDPC of leaf blight by 47% as compared to the untreated control, and by 47% as compared to $1000 \text{ ml of sulphur ha}^{-1}$ without Zn (Table 4.7). No significant linear relationship was found between AUDPC and sulphur rate for plots treated with either rate of Zn (Fig. 4.10a). Sulphur by itself or with Zn did not reduce severity of leaf blight at La Libertad in 1996.

Effects of *Si* Plus Triazophos on the Incidence of Neck Blight

Santa Rosa 1995 The incidence of neck blight was reduced by Si at 1000 kg ha^{-1} for all rates of triazophos, when compared to $0 \text{ kg of Si ha}^{-1}$ (Fig. 4.9) (Table 4.8). Sulfur at 1000 kg ha^{-1} , without triazophos, reduced incidence of neck blight by 19% as compared to the untreated control (Fig. 4.9). Triazophos at 300 g ha^{-1} without Si , reduced neck blight by 46%. Treatment with Si at 1000 kg ha^{-1} plus $30 \text{ g of triazophos ha}^{-1}$ reduced the incidence of neck blight to the same statistical level (Fig. 4.9) as the full rate of triazophos without Si (Table 4.8). For plots treated with Si or $1000 \text{ kg of Si ha}^{-1}$, the relationship between incidence of neck blight and rate of triazophos was significant (Fig. 4.10b) and cubic (Fig. 4.11a). Incidence of neck blight was reduced by 44% and 62% for plots treated with Si or $1000 \text{ kg of Si ha}^{-1}$, respectively, when the rate of triazophos was raised from 300 g ha^{-1} .

Santa Rosa 1996 The incidence of neck blight was, on average, 20% higher in 1996 than in 1995 at Santa Rosa. Applications of Si at 1000 kg ha^{-1} significantly reduced the incidence of neck blight by 34% and 37% as compared to 0 kg ha^{-1} for the 0 and 30 g

Table 4.5 Effects of nitrate plus fungicide applied at fall and reduced rates on the incidence of root blight and yield of rough rice at Santa Rosa in 1994

| Nitrate kg ha ⁻¹ | Fungicide mg ^a | % Incidence root blight | Yield kg ha ⁻¹ |
|--------------------------------|------------------------------|----------------------------|------------------------------|
| 0 | 00 | 34 a ^b | 1712 d |
| 0 | 100/00 | 35 c | 1870-abc |
| 0 | 250/00 | 33 ab | 2080-ab |
| 0 | 500/000 | 29 cd | 2273 ab |
| 1000 | 00 | 46 b | 1827 abc |
| 1000 | 100/00 | 34 cd | 2077 a |
| 1000 | 250/00 | 36 d | 2063 abc |
| 1000 | 500/000 | 18 e | 2140 a |

^aRates of nitrofen (5, 10 %), applied at sowing and prochloraz, and tricyclozole (5 kg ha⁻¹), applied at heading, 1 % heading, and 50 % heading.

^bYield of rough rice, adjusted to 12% moisture content.

^cComparisons of any two values in the same column followed by the same letter do not differ significantly ($P < 0.05$) as determined by t tests on least-squares means. Each value is the mean of five replications.

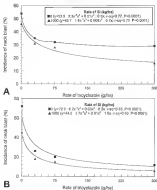


Figure 4.11: Relationship between the incidence of pink blot-PH of rice and rate of methylazoxystyrene applied to the susceptible and non-susceptible rice varieties (rice, Colombia A/ 1994 and B/ 1996). Each point is the mean of five replications.

to 1 rate of tripyrazole, respectively at Santa Rosa in 1996 ($P < 0.01$) (Table 4-8). Neck blight was reduced by 51 to 1000 kg ha $^{-1}$ when compared to the untreated control ($P < 0.01$) (Table 4-8). Tripyrazole at 300 g ha $^{-1}$, without Si, reduced neck blight by 33% as compared to the control and by 73% as compared to Si without tripyrazole, however, the combination of Si plus tripyrazole at 10 g ha $^{-1}$ reduced neck blight to the same untreated level as the full rate of tripyrazole without Si (Table 4-8). The relationship between incidence of neck blight and rate of tripyrazole was both significant ($P < 0.0001$) and cubic for plots amended with 1000 kg of Si ha $^{-1}$, as well as plots not treated with Si ($P < 0.0001$). Neck blight was reduced by 57% and 88% for the three 1000 kg ha $^{-1}$ rates of Si, respectively, as the rate of tripyrazole was increased from 0 to 300 g ha $^{-1}$.

La Libertad 1995: As with leaf blight, levels of neck blight were lower at La Libertad than at Santa Rosa. Neck blight was reduced by the application of Si at La Libertad in 1995. Differences in incidence between the two rates of Si were significant at the 0 g ha $^{-1}$ rate of tripyrazole only ($P < 0.01$) (Table 4-10). The incidence of neck blight was 11% lower for Si without tripyrazole when compared to the untreated control, and did not differ significantly from 300 g of tripyrazole ha $^{-1}$ without Si (Table 4-10). The relationship between the incidence of neck blight and rate of tripyrazole was significant and linear ($P < 0.01$) for plots amended with Si ($P < 0.0001$). As the rate of tripyrazole was increased from 0 to 300 g ha $^{-1}$, incidence of neck blight decreased by 63%. No significant differences in the incidence of neck blight were observed for any rate of tripyrazole on plots amended with 1000 kg ha $^{-1}$ Si ($P < 0.126$).

La Libertad 1996: Si reduced the incidence of neck blight at La Libertad in 1996, with overall incidence of neck blight being higher than in 1995 (Table 4-11). Neck blight

Table 4.9 Effects of nitrate plus fungicide applied at full and reduced rates on the economics of peak flow and yield at rough rice at Ikoma flow in 1995

| RI | Fungicide | % Incidence | Yield |
|---------------------|-------------------|----------------------|-----------------------|
| kg ha ⁻¹ | rate ^a | perk ha ^b | kg ha ⁻¹ c |
| 0 | 0.0 | 72 ef | 3264 d |
| 0 | 100/30 | 26 e | 3769 cd |
| 0 | 250/15 | 26 cd | 3777 cd |
| 0 | 1000/300 | 12 ef | 3902 bc |
| 1000 | 0.0 | 64 b | 3435 a |
| 1000 | 100/30 | 18 ab | 3275 ab |
| 1000 | 250/15 | 15 ab | 3482 a |
| 1000 | 1000/300 | 6 f | 3340 ab |

^a Rates of ethionazole (E. ha⁻¹), applied at flowering and panicle initiation and tricyclazole (Z. ha⁻¹) applied at booting; 0% booting, and 50% booting

^b Yield of rough rice, adjusted to 12% moisture content

^c Comparisons of any two values in the same column followed by the same letter do not differ significantly ($P=0.05$) as determined by t-test in least-squares means. Each value is the mean of five replications.

Table 4.10 Effects of nitrate plus fungicide applied at fall and reduced rates on the incidence of root blight and yield of rough rice at U.S. Laboratory in 1993

| N ^a kg/ha ¹ | Fungicide rate ^b | % Incidence root blight | Yield ^c kg/ha ^{1/2} |
|--------------------------------------|--------------------------------|----------------------------|--|
| | | | |
| 0 | 00 | 4.0 a ^d | 1777 b |
| 0 | 100/00 | 3.3 ab | 1834 b |
| 0 | 250/75 | 2.8 bc | 1771 b |
| 0 | 1000/300 | 1.3 c | 1883 b |
| 1000 | 0/0 | 1.8 bc | 2023 a |
| 1000 | 100/00 | 1.8 bc | 2008 a |
| 1000 | 250/75 | 0.75 c | 2046 a |
| 1000 | 1000/300 | 0.75 c | 2128 a |

^aRate of nitrophenol (1.8a %), applied at tillering and panicle initiation, and imazafosfate (1.8a %), applied at heading, 75% heading, and 30% heading

^bYield of rough rice, adjusted to 12% moisture content

^cComparisons of any two values in the same column followed by the same letter do not differ significantly ($P=0.05$) as determined by *t* tests on least-squares means. Each value is the mean of five replicates

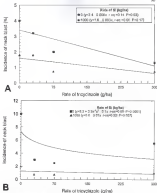


Figure 4.15. Relationship between the incidence of root blight of rice and rate of fungicide applied to Seiravankal and non-irrigated plots at La Libertad, Colombia in AG 1991 and AG 1996: each point is the mean of five replicates.

Table 4.10 Effects of release plus fungicide applied at full and reduced rates on the incidence of root blight and yield of rough rice at La Taborda in 1996

| R ₁ | Fungicide | % Incidence | Yield |
|---------------------|-----------------|--------------------|---------------------|
| kg ha ⁻¹ | mg ² | root blight | kg ha ⁻¹ |
| 0 | 00 | 9.3 a ¹ | 2635 b |
| 0 | 100/00 | 3.3 bc | 2619 b |
| 0 | 250/00 | 2.5 c | 2600 b |
| 0 | 1000/000 | 0.0 d | 2636 ab |
| 1000 | 0/0 | 2.0 c | 2511 a |
| 1000 | 100/00 | 0.0 c | 2547 a |
| 1000 | 250/00 | 0.0 c | 2596 b |
| 1000 | 1000/000 | 0.0 c | 2622 ab |

¹Rate of fungicide (L ha⁻¹) applied at sowing, seed germination initiation, and transplanting (g ha⁻¹) applied at heading, 15% heading, and 30% heading.

²Yield of rough rice, adjusted to 12% moisture content.

³Comparisons of any two values on the same column followed by the same letter do not differ significantly ($P < 0.05$) as determined by *t*-tests on least-squares means. Each value is the mean of five replications.

was lower (0 and 300 g ha⁻¹ tripyrazole plus 1000 kg of S₂ ha⁻¹) as compared to the same rates of tripyrazole without S₂ (P<0.05) (Table 4.11). Treatment with S₂ at 1000 kg ha⁻¹ without tripyrazole reduced root blight by 73% as compared to the untreated control, and by 64% as compared to 300 g of tripyrazole ha⁻¹ without S₂ (P<0.05). At 0 and 1000 kg ha⁻¹ S₂, root blight was significantly reduced by 49% and 58%, respectively, as the rate of tripyrazole was increased from 0 to 300 g ha⁻¹ (Fig. 4.12b). The relationship between the incidence of root blight and rate of tripyrazole was quadratic in plots not treated with S₂, and linear for those amended with 1000 kg of S₂ ha⁻¹.

Effects of S₂ plus Flupyradifosfen on Yield

Early Season. Yields of rough rice were increased by the application of S₂ in both years of the study (Tables 4.13-4.15). S₂ at 1000 kg ha⁻¹, without flupyradifosfen, significantly increased yields by 44% and 33% as compared to the untreated control in 1993 and 1994, respectively (P<0.05) (Tables 4.13-4.15). In 1995, yields from plots treated with full rates of ethionaphos and tripyrazole without S₂ were higher than those of the untreated control (P<0.05), and did not differ significantly from 1000 kg of S₂ ha⁻¹ without flupyradifosfen (Table 4.15). In 1996, S₂ at 1000 kg ha⁻¹ without flupyradifosfen increased yields as compared to full rates of ethionaphos and tripyrazole without S₂ (P<0.05) (Table 4.15). In 1995, the relationship between yield and rate of flupyradifosfen was significant only for flupyradifosfen applied without S₂ (Fig. 4.13a). Ethionaphos and tripyrazole, applied without S₂, raised yields by 125% at the highest rate when compared treatments without S₂ or flupyradifosfen (P<0.005) (Fig. 4.13a). No significant change (P>0.10) in yield could be associated with increased rates of flupyradifosfen applied to plots treated with 1000 kg of S₂ ha⁻¹ in 1995. In 1996, the application of flupyradifosfen at reduced or full rates did not significantly affect

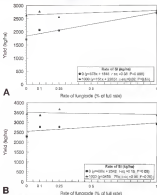


Figure 4.13: Relationship between yield of rough rice (kg/ha) and rate of fertilizers (rates 0, 10, 25, or 100% of the recommended rate of 1.1 ha^{-1}) plus fungicide (rates 0, 10, 25, or 100% of the recommended rate of 300 g ha^{-1}) applied to Ss (unseeded) and non-transgenic plots at Santa Rosa, Colombia in A) 1991 and B) 1992. Each point is the mean of five replications.

yield in plots not treated with Zn or plots amended with 1000 kg of Zn ha^{-1} (Fig. 4.13a).

Yields for all treatments were greater in 1995 than in 1993.

La Libertad. Yields of rough rice were lower at La Libertad than at Santa Rosa in both 1995 and 1996. Zn at 1000 kg ha^{-1} , without fungicide, increased yields by 28% in 1995 and 1996 as compared to the untreated control ($P < 0.05$) (Tables 4.10 and 4.11). At each rate of fungicide in 1995, yields were significantly higher for 1000 kg of Zn ha^{-1} as compared to 0 kg of Zn ha^{-1} (Table 4.13). In 1996, yields from plots treated with 0 or 1000 kg ha^{-1} , without fungicide, were significantly increased by 23% as compared to plots treated with full rates of nitrophosphorus and fungicide without Zn ; however, in 1996, no differentiation yield were found between the above-mentioned treatments ($P < 0.05$) (Tables 4.10–4.11). The relationship between yield and rate of fungicide was significant ($P < 0.04$) and lower for plots not treated with Zn , or plots amended with 1000 kg of Zn ha^{-1} (Fig. 4.14a). For both rates of Zn , yields decreased by up to 7% as the rate of fungicide was increased to the maximum. In 1996, the relationship between yield and rate of fungicide was not significant for either rate of Zn , indicating that yield was not significantly different among the rates of fungicide tested ($P < 0.20$) (Fig. 4.14b).

Analyzed Effects of Zn on Leaf Nitrogen, Nitrogen Use, and Yield

Santa Rosa. Applications of Zn made in 1993 reduced the severity of leaf blight in 1995 (Table 4.12). Sulfone applied in 1995 reduced AUDPC of leaf blight by 58% as compared to the untreated control ($P < 0.0001$) (Table 4.12). Mean values of AUDPC did not differ significantly between plots treated with Zn in 1993-treated plots) and plots treated in 1994, or between plots treated with only 1000 ml of nitrophosphorus ha^{-1} ($P < 0.05$) (Table 4.12). Fresh applications of Zn in combination with nitrophosphorus significantly

Table 4.12 Comparisons made in 1996 at Santa Rosa and La Libertad, Colombia, of area under the disease progress curve (AUDPC) of leaf blight from rice treated with urea (U) or 1000 kg ha⁻¹ in 1995 (residual S₀) with selected treatments of either fresh S₀ (applied at 1000 kg ha⁻¹ in 1996) or residual S₀ plus the labeled rate of nitrophos (1000 g ha⁻¹)

| Comparisons ^a | AUDPC | |
|---|----------------|-------------|
| | Santa Rosa | La Libertad |
| Residual S ₀ 1995 application (1000 kg ha ⁻¹) vs | 2.13 | 0.54 |
| 1996 Treatments | | |
| Unselected control (no S ₀ , no fungicide) | 4.30 (S 0004)† | 0.12 (S 04) |
| Fresh S ₀ —1996 application (1000 kg ha ⁻¹) | 2.50 (S 06) | 0.30 (S 08) |
| No S ₀ + full rate of nitrophos (1000 g ha ⁻¹) | 2.76 (S 08) | 0.75 (S 09) |
| Residual S ₀ (1995 application) + full rate of nitrophos (1000 g ha ⁻¹) | 3.04 (S 11) | 0.16 (S 04) |
| Fresh S ₀ (1996 application) + full rate of nitrophos (1000 g ha ⁻¹) | 3.39 (S 13) | 0.19 (S 05) |

^aValues in tables are mean values of AUDPC of leaf blight collected in 1996 from residual plots treated with S₀ in 1995 and planted in rice in 1996. Comparisons are made between AUDPC's of leaf blight from residual plots and selected treatments made in 1996.

†Numbers in parentheses are P values from comparisons between AUDPC's of leaf blight from residual plots and selected treatments made in 1996. For a given comparison, means are considered to be significantly different if P < 0.05, based on t-tests of the means in each comparison.

reduced AUDPC of leaf blight when compared with untreated plots without fungicide ($P<0.05$).

The incidence of neck blight in 1998 was reduced by 40% in plots treated with 1000 kg ha⁻¹ Zn in 1995, as compared to the untreated control ($P<0.0001$) (Table 4.12). No significant differences occurred in the incidence of neck blight between plots treated with Zn in 1995 and those treated in 1996 ($P>0.05$), however, the incidence of neck blight was higher in residual plots than in plots treated with 300 g of imazapyridine ha⁻¹ only ($P<0.0001$) (Table 4.13). The addition of reduced rates of imazapyridine to residual plots did not control neck blight as well as the full rate of imazapyridine without Zn. In general, all plots that treated with chlorophen, with or without application of Zn in 1995, significantly reduced AUDPC when compared to residual plots without fungicide.

significantly reduced AUDPC when compared to residual plots without fungicide

First applications of Zn were more effective in increasing yield in 1998 at Davis than applications of Zn made in 1995. Although yields of rough rice from residual plots were 22% higher than yields from the untreated control ($P<0.0004$), they were lower than yields from plots treated with Zn in 1995 ($P<0.04$) (Table 4.13). Yields from residual plots did not differ significantly from those of plots treated only with full rate of chlorophen and imazapyridine ($P>0.05$) (Table 4.12).

Leaf blight. At La Grana, Baja, applications of Zn made in 1995 reduced the severity of leaf blight, as measured by AUDPC, in 1998. The AUDPC of leaf blight from plots treated with 1000 kg of Zn ha⁻¹ in 1995 was lower than for untreated controls ($P<0.04$) (Table 4.12). Severity of disease in residual plots was not significantly different from that in plots treated with first applications of Zn or with chlorophen at 1800-ml ha⁻¹ without Zn ($P>0.05$) (Table 4.12).

Table 4.15. Comparison made in 1996 at Santa Rosa and La Libertad, Colombia, of the incidence of neck blight and yield from rice treated with silicon (Si) at 1000 kg ha⁻¹ in 1993 (treated Si) and then with selected treatments of carbon that Si supplied at 1000 kg ha⁻¹ in 1993 or avoided Si plus the labeled rate of insecticide (200 g ha⁻¹)

| Comparisons ^a | Santa Rosa | | La Libertad | |
|---|-------------------------------|------------------------------|-------------------------------|------------------------------|
| | Neck blight percentage (%) | Yield kg ha ⁻¹ | Neck blight percentage (%) | Yield kg ha ⁻¹ |
| Treated Si - 1993 application (2000 kg ha ⁻¹ Si) | 41.0 | 2607 | 7.0 | 2734 |
| Treated (control (no Si, no insecticide) | 11.2 (p<0.001) ^b | 2584 (p=0.616) | 9.1 (p=0.61) | 2620 (p=0.72) |
| Neck Si - 1994 application (2000 kg ha ⁻¹) | 44.1 (p=0.0) | 1844 (p=0.0) | 2.0 (p=0.0) | 3238 (p=0.000) |
| Neck Si + full rate of insecticide (200 g ha ⁻¹) | 22.1 (p<0.001) | 2003 (p=0.0) | 9.4 (p=0.0) | 2610 (p=0.001) |
| Neck Si (Si 1993 application) + full rate of insecticide (200 g ha ⁻¹) | 9.02 (p<0.001) | 1981 (p=0.0) | 1.4 (p=0.0) | 3077 (p=0.001) |
| Neck Si (Si 1994 application) + full rate of insecticide (200 g ha ⁻¹) | 0.21 (p=0.000) | 2387 (p=0.0) | 1.0 (p=0.0) | 3051 (p=0.0) |

^aValues in columns are mean values of six clones of neck blight and yield of rice collected in 1996 from treated plots (treated with Si in 1993 and planted for rice in 1996).

Comparisons are made between values of incidence of neck blight and yield of rice from treated plots and selected treatments made in 1996.

Numbers in parentheses are P values from comparisons between values of neck blight and yield of rice from treated plots and selected treatments made in 1996. For a given comparison, means are considered to be significantly different if P < 0.05, based on trials of the two means in each comparison.

The incidence of neck blight in residual plots was significantly reduced by 65% as compared to untreated treated plots ($P < 0.001$) (Table 4.11). Neck blight was lower on plots that received 1000 kg of N ha^{-1} in 1994 than in residual plots ($P < 0.05$). In 1995, the incidence of neck blight from plots treated with 300 g of metachloro ha^{-1} was not different from that observed in residual plots ($P > 0.10$) (Table 4.12).

Applications of N made in 1993 did not significantly increase yields in 1994 as compared to untreated control plots ($P > 0.05$) (Table 4.13). Yields from plots amended with 1000 kg of N ha^{-1} in 1994 were 12% higher than in residual plots ($P < 0.001$), but no significant differences in yield were found between residual plots and those treated with the labeled rate (300 g ha^{-1}) of metachloro ($P > 0.05$) (Table 4.13).

Correlation Analysis between Yield and Disease

Yield was related to leaf and neck blight at Santa Rosa in 1993 and 1994 (Table 4.14). The correlation between yield and both leaf and neck blight was found to be negative and significant ($P < 0.001$ and $P < 0.001$). At La Libertad, only leaf blight reduced yields in both years of the study. Significant correlations were found between yield and leaf blight in 1993 ($r = -0.883$, $P < 0.001$), however, no significant relationship was noted between yield and neck blight at La Libertad ($r = -0.17$, $P > 0.10$) (Table 4.14).

Content of N in Plant Tissues

Shoots content in leaf tissue for individual treatments did not differ significantly between evaluation dates ($P > 0.05$), therefore means are presented as an average across all evaluations made at Santa Rosa and La Libertad in 1994 (Table 4.15). The interaction between rate of N and rate of fungicide was not significant in either locations, thus N content was averaged across all rates of fungicide for the 0 and 1000 kg N ha^{-1} rates of N .

Table 4.14 Pearson correlation coefficients for yield vs. severity of leaf blight and incidence of neck blight disease at Santa Rosa and La Libertad, Colombia in 1995 and 1996

| Yield ^a | Pearson correlation coefficient | | | |
|--------------------|------------------------------------|---|------------------------------------|---|
| | 1995 | | 1996 | |
| | Leaf blight ALDPPC ^b | Neck blight Incidence (%) ^c | Leaf blight ALDPPC ^b | Neck blight Incidence (%) ^c |
| Santa Rosa | -0.67 | -0.47 | -0.52 | -0.54 |
| F-test > (F) | 0.0001 | 0.001 | 0.0006 | 0.0008 |
| $n=40$ | | | | |
| La Libertad | -0.68 | -0.502 | -0.24 | -0.18 |
| F-test > (F) | 0.0001 | 0.07 | 0.63 | 0.31 |
| $n=40$ | | | | |

^aYield of single row (kg ha⁻¹) from 'Geyron 1' and 'Luzon 2' planted at Santa Rosa and La Libertad, respectively

^bArea under disease progression curve (ALDPPC) used as a measure of severity of leaf blight

^cPercent incidence of neck blight, mean of 10 panicles per plot

Table 4.15. Content of Si in leaf and stem tissue of rice collected in 1996 from plots amended with Si (1000 kg ha⁻¹) in 1993 and 1996 at Santa Rosa and La Laboral, Colombia

| Location | Application | Si rate kg ha ⁻¹ | 1996 Si content (mg kg ⁻¹) ^a | |
|------------|---------------------|--------------------------------|---|-----------|
| | | | Leaf | Stem |
| Santa Rosa | 1996 | 0 | 2.10 a ^b | 2.84 a |
| | | 1000 | 2.83 b, A | 3.60 b, A |
| Santa Rosa | 1993 (irrigated) | 0 | 2.35 a | 2.84 a |
| | | 1000 | 2.13 b, B | 3.56 b, A |
| La Laboral | 1996 | 0 | 1.91 a | 1.83 a |
| | | 1000 | 3.78 b, A | 3.20 b, A |
| La Laboral | 1993 (irrigated) | 0 | 2.24 a | 1.85 a |
| | | 1000 | 2.91 b, B | 1.97 b, B |

^aConcentration of Si in dryweight (mg)/per kg of leaf or stem tissue

^bThe comparisons of Si concentrations in tissue from plots treated in the same year, irrigation-irrigated versus rice of longgrain for a given location, and are followed by lower case letters. The comparisons of Si concentrations in tissue from irrigated (1993 application) and flooded (1996 application) plots, versus are irrigated versus rice of longgrain and are followed by upper case letters. Comparisons of any two values followed by the same letter and case do not differ significantly ($P=0.05$) as determined by t-test performed on least squares means.

At both Santa Rosa and La Libertad, Si content was higher in both leaf and stem tissue from plots treated with 1000 kg of Si ha⁻¹ in 1994 when compared to untreated plots, the content of Si was 10% and 20% higher in leaf and stem tissues, respectively, from Santa Rosa, while Si content increased by 30% and 40%, respectively, in leaf and stem tissue from La Libertad ($P < 0.05$) (Table 4.13).

Silicon content of leaf and stem tissue was higher in 1994 from samples taken from residual plots at both locations, as compared to untreated plots ($P < 0.05$) (Table 4.12). At both Santa Rosa and La Libertad, content of Si in leaf tissue was greater in samples collected from plots treated with Si in 1994 than in samples from residual plots ($P < 0.05$) (Table 4.13). There was no significant difference in the content of Si in stem tissue between plots amended with Si in 1994 and residual plots at Santa Rosa ($P > 0.05$), while Si content in stem tissue was significantly higher for Si applied in 1994 as compared to that applied in 1998 (Table 4.14). Silicon content of leaf tissue was 30% lower in samples from residual plots as compared to plots treated with Si in 1994 at Santa Rosa. At La Libertad, Si content in leaf and stem tissue dropped by 33% in residual plots as compared to plots treated in 1994 with 1000 kg ha⁻¹ Si.

Discussion

The severity of leaf blight, as general, was approximately 50% higher at Santa Rosa in 1993 than in 1995. The percent diseased leaf area in the final disease evaluation of that site in 1993 was 47% in untreated control plots, and decreased to 21% in 1995. The AUDPC for leaf blight were 50% lower in 1994 than in 1993 at Santa Rosa. At La Libertad, final disease never exceeded 12% in untreated controls in either year of the study and the AUDPC for leaf blight was 50% lower in 1994 than in 1993. Although

year to year variation in levels of incidence may have been responsible for the decrease in severity of leaf blight at Santa Rosa in 1994; it is more likely that a late planting date contributed to the decline. Delayed date of planting, unknown to reduce severity of leaf blight, and is commonly used as a means of control for the disease [14,15]. Planting was delayed by nearly 3 weeks at Santa Rosa in 1994 due to heavy rains. By the time of emergence, the optimal period for development of leaf blight, normally in May and early June, had passed, and delay in planting resulted in lower levels of disease. Severity of leaf blight is inherently higher at Santa Rosa than at La Libertad, mostly because of the presence of the upland rice breeding nursery maintained by CLAT and the large history of rice cropping at that location [14]. These two factors serve to maintain a high level of inoculum throughout the cropping season. Also the cultivar planted at La Libertad was chosen because of its high degree of susceptibility to a race of *M. grisea* thought to be present at high frequency at that location; however, this proved to be incorrect, and levels of leaf blight were lower than anticipated. The incidence of neck blight at Santa Rosa was higher in 1994 than in 1993, possibly due to late season rains in 1994. As with leaf blight, the incidence of neck blight was very low at La Libertad in both years of the study.

Applications of *Bi* and *abiglyphon* had a significant effect on disease progress during 1993 and 1994 at both locations of the study. Efforts to control plant diseases such as blight are usually classified into those which reduce initial inoculum, or those which slow the rate of disease progress [4] over time [23,27]. At Santa Rosa and La Libertad, most of disease occurred before the first application of *abiglyphon* in both 1993 and 1994, indicating that neither *Bi* nor *abiglyphon* had any appreciable effect

or initial disease (y_0). The fully rate of progress of leaf blight (y_0), obtained from Gompertz-transformed disease progress curves (35), was approximately 30% lower at 30 t/ha of plants than in untreated plots, regardless of the rate of abscisic acid applied. Likewise, r_0 was reduced as the rate of abscisic acid was increased; however, the magnitude of the reduction was greater when abscisic acid was applied without 30 than when applied with 30. It is possible that the stronger effect of 30 results in dampens the effect of fungicides when the two are applied together. The overall effect of abscisic acid on y_0 at low levels of initial severity (La Laborie) was not significant. It appears that the effect of 30 on y_0 is greater than that of abscisic acid, even at high levels of severity. Both 30 and fungicides treatment suppress disease progress, resulting in smaller AUDPC's and lower levels of leaf lesions when compared to untreated controls.

Control practices that reduce risk to the production of secondary inoculum of a given pathogen on the host (32). Fungicides accomplish this by reducing the efficiency (the ability to produce secondary lesions) of secondary inoculum by directly inhibiting pathogen spores and viable stages of infection (37). Thus, fewer propagules are available to contribute to the epidemic, and the rate is then reduced. In the present study, the reduction in epidemic rate associated with applications of 30 are indicators of some effect on the interaction between *M. grisea* and the rice plant. Evidence is not directly made to *M. grisea* (personal observations, data not shown), indicating that the mechanism by which r_0 of leaf blight is reduced by 30 may be the enhancement and/or strengthening of resistance to rice blast. As defined by Pethenker (33,34), the components of resistance that reduce the epidemic rate are decreased infection efficiency (number of sporulating lesions per unit of inoculum), increased latent period (time

to more arrival of nematodes and potentially reduced lesion size, and decreased nematodes per lesion. Elseon, following uptake from the soil, is deposited in epidermal cells and beneath the outside of the epidermis (47,116). Several researchers have suggested that deposited *Is* acts to form a barrier to ingests by *M. grisea* (40,11,122) which could potentially reduce infection efficiency. Yello et al. (148) hypothesized that *Is* forms complexes with organic molecules in epidermal walls, and that these compounds inhibit development of *M. grisea* within the host. This then could reduce infection efficiency and lesion expansion, and thus total reproduction of the pathogen. Other workers have suggested that *Is* acts as a trap such as nematodes and larvae to stimulate host defense mechanisms to pathogenesis such as the production of phenols and lipoxygenase (24,36,102). These molecules, if present in the nematode, could potentially affect the structure of components of resistance to lesion. Elseon, both in the field and greenhouse, studies effects of *Is* on selected components of resistance to *M. grisea* would be useful to better understand how *Is* acts to reduce nematode.

The application of *Is* proved to be an effective means of controlling leaf and root blight in upland rice under conditions of low and high severity of disease in eastern Colombia in 1993 and 1994. *Is* applied at a rate of 1000 kg ha⁻¹ significantly reduced leaf and root blight in response to untreated controls at Santa Rosa and La Libertad, confirming previous reports (29,45,47,123,124). Regardless of the rate of fungicide applied, the percentages of *Is* in leaf tissue collected during the leaf blast epidemic and stem tissue collected at harvest from *Is* treated plots were significantly higher than in leaves from untreated plots in both years and at both locations. Because the level of infection was adjusted in untreated controls to that of *Is* treated plots, it can be concluded

that control of blast in this study was due to the presence of Si in plant tissue. Dethloff *et al.* (1972) analysed leaf samples from defoliated plants and found no increase in calcium as the rate of calcium uptake was increased, whereas the level of Si in tissue did increase. In general, the percentage of Si in leaf and stem samples from untreated control plants at La Libertad was lower than from their counterparts at Santa Rosa. This is a reflection of the amount of plant-available Si in the soils at both locations. Santa Rosa appears to have a slightly higher level of plant available Si than La Libertad. The response of leaf and stem tissue to fertilization with Si at Santa Rosa was of a lower magnitude than at the highly Si-deficient site at La Libertad.

One of the primary goals of this study was to determine if Si could control leaf and neck blast as well as the recommended rates of two fungicides commonly used in Colombia, and if not, whether control of blast could be enhanced by applying reduced rates of these fungicides in conjunction with Si. When compared to the fungicide combinations, applied at full and reduced rates, Si reduced the AUDPC of leaf blast and the amount of final disease to the same level as the recommended rate of azoxystrobin (3 L ha⁻¹) at Santa Rosa in 1993, and provided significantly better control of leaf blast than the fungicide in La Libertad in 1993 and 1996 and at Santa Rosa in 1996. It is clear that the performance of Si against leaf blast depended somewhat on higher levels of disease, however, efficacy remained equal to the full rate of fungicide. Dethloff *et al.* (1972) demonstrated that each liter of Fisons could be converted as effectively with 2-300 kg of Si ha⁻¹ as with benomyl at 1-60 kg ha⁻¹. In the present study, 4000 kg of Si ha⁻¹ significantly reduced the incidence of neck blast as compared to untreated controls at both locations in 1994 and 1996. However, only at La Libertad, at both years of the

study, did the level of control equal or exceed that of the fall rate of triazophos (200 g ha⁻¹) applied without Se.

The addition of a 10% rate of triazophos prior to or 1000 kg ha⁻¹ however, reduced the incidence of seed blight to the mean untreated level at the fall rate of fungicide at Santa Rosa in both 1995 and 1996. Based upon these results, it appears that the application of fungicides to control leaf blight on rice grown on Se-deficient soils could be eliminated by Se fertilizers, even in areas with high incidence levels of blight. In the case of seed blight, high levels of disease severity may require a higher rate of Se, or the addition of a fungicide such as triazophos at a reduced rate. From the field study reported in Chapter 2 of this dissertation, it was learned that fungicides applied in specific timings, especially at heading and early heading, provided control of blight as well as fall spray schedules consisting of five applications. In that study, the application of Se at 400 kg ha⁻¹ proved to be insufficient for the control of seed blight under conditions of high severity of disease, as compared to untreated controls. A possible strategy for disease control could be based upon an understanding of the Se level in the soil for a given area and the history of disease severity. From this, the ideal rate of Se for a particular area could be determined and integrated with reduced rates of fungicide, applied at critical timings, to manage blight more effectively.

As has been demonstrated previously, depending upon the location, the application of Se to Se-deficient soils increased yield 20-150%, as compared to untreated control plots (48,43-46, 73, 152). More importantly, in each location in 1993 and 1996, yields from plots that had been treated with 1000 kg of Se ha⁻¹ were either statistically equal to or greater than yields from plots treated with recommended rates of nitrogen

and trypsinoids. It appears possible to eliminate applications of fungicide entirely, as long as an adequate amount of Zn fertilizer is employed on Zn -deficient soils. As with control of leaf and neck blast, it is noted that large quantities of Zn to control levels of disease severity are high. This is illustrated from results obtained at Santa Rosa in 1994 (Chapter 3). The application of only 400 kg of Zn ha⁻¹, which was adequate for control of blast and improvement of yields in locations with low severity of disease, did not reduce blast as compared to untreated controls. However, yields increased under conditions of high severity of disease. By raising the rate of Zn fertilizer in 1995 and 1996 to 1000 kg ha⁻¹, disease control and yields improved untreated controls and fungicides. The extent of blast as the indicator of yield deficiency located in this study. At Santa Rosa, where the severity of blast was much greater, significant negative correlations were determined between yield and severity of leaf and neck blast. Correlation coefficients were roughly the same for leaf blast and neck blast, therefore, leaf blast and neck blast were most likely of equal importance in disease to yield reduction. Leaf blast was the major yield-reducing form of blast at La Libertad. It is generally accepted that neck blast is the most destructive phase of rice blast (14); however at La Libertad, no significant correlation was found between yield and neck blast in 1995 or 1996. The lack of correlation between yield and neck blast is a function of the overall low levels of blast observed at La Libertad in both years of the study, and may also indicate that the onset of neck blast occurred too late to affect grain fill significantly.

Applications of Zn made in 1991 were found to have significant residual activity against leaf and neck blast in 1994 at Santa Rosa and La Libertad, confirming previous reports (40). At both locations, the AUDPC of leaf blast was significantly lower in

residual phosphorus as 1994 with 5g than in untreated plots, and did not differ significantly from 45/100C of total from plots treated with 5g in 1996. It was necessary to apply the full rate of inorganic forms residual phosphorus in 1996, and a 100% rate in La Libertad, to control with them as well as fresh applications of 5g. However, nitrogen of residual was still significantly lower in residual plots than in untreated control plots at both locations. Sulphur recovery remained in residual plots at El Estero and La Libertad to meet yields significantly in comparison with controls, despite the better performance of fresh applications of 5g plots made in 1996. Most importantly, yields from residual plots were not significantly different than yields from plots treated with the full rates of nitrophosph and triphosphate. Although yields were higher (by as much as 100%) where fresh applications of 5g were made than in residual plots, the level of 5g in soil a year following treatment with 5g is adequate for disease control and yield enhancement. This is illustrated by measurements of the content of 5g in plant tissue collected during the growing season and at harvest.

In all cases, 5g content was greater in leaf and stem tissue collected from plots treated with 5g in 1996 than in tissue from untreated plots, but the amount of 5g in tissue from residual plots was always greater than from samples collected from untreated control plots. The residual activity of 5g observed for two soil types under the cultivation of upland rice suggests that it may be possible to repeat annual applications of 5g for rice. The amount of 5g applied in this study, 1200 kg ha⁻¹, represents a significant input, both in volume and cost. In the upland non-growing regions of Colombia, there are no readily available sources of 5g fertilizer (Dr P. Correa, personal communication). The application of 5g over a 2-year (or longer) schedule would make the use of this material

more extensive in growers, not only in Colombia, but in other regions where upland rice is grown. Further research is needed to determine the rate of decline of Si in soils following applications of Si, and the consistent effects on disease and yield. Basal soil fertility of Si could be supplemented with fertilizers (possibly at reduced rates) or by periodic additions of silicon sources, or other sources of Si such as crop residues, that would allow the optimal level of plant-available Si to be maintained in Si-deficient soils.



CHAPTER V
DISEASES AND YIELD RESPONSE IN SUSCEPTIBLE, PARTIALLY
RESISTANT, AND RESISTANT RICE CULTIVARS FOLLOWING FERTILIZATION
WITH CALCIUM SILICATE

Introduction

Cultivars of rice (*Oryza sativa* L.) with complete resistance to rice blast, caused by *Magnaporthe oryzae* (Shiwo) that have been deployed successfully to manage this disease, especially in areas where blast is sporadic or low in severity (17,31,118). However, individual resistant cultivars historically have become susceptible to blast within a short time after their introduction due to the emergence of pathogen races of *M. oryzae* that are no longer affected by resistance genes in the host (35,118). Thus as a result of inherent variability in populations of *M. oryzae*, an ability to select and advance breeding lines for the presence of populations of *M. oryzae* that are representative of those encountered in commercial fields (34,36,122).

Complete resistance, called vertical resistance by van der Plank (342), is typically controlled by single major resistance genes in the host plant and is specific to individual races of a pathogen (34-35). As such, this type of resistance is likely to be overcome sufficiently by the appearance of races of the pathogen that do not possess corresponding genes for avirulence (114,116,140). Cultivars that are partially resistant to blast have also been utilized to control blast in irrigated lowland rice in tropical regions, but have performed poorly in areas with greater blast severity, such as irrigated lowland rice in temperate regions and upland rice systems (34,122).

Partial resistance is controlled by multiple genes, called *minor genes* or *quantitative trait loci*, and tends to be effective against multiple races of a pathogen (11,13,14,16). Thus, partially resistant cultivars tend to have more *field* resistance, however, partial resistance may be environmentally sensitive and partially resistant cultivars that perform well in one climate may be more susceptible in another climate (16,17). Under conditions that are highly conducive to the development of rice blast, additional disease control strategies, such as cultural practices or fungicides, are needed (17,36). Recently a durably resistant rice cultivar, *Oryza Linnae 5*, has been identified that possesses multiple *major genes* for resistance to blast, as well as genes for partial resistance. This cultivar had been selected in areas with a diverse population of races of *M. grisea* and is still highly resistant to blast nearly 10 years after its introduction (34).

Upland rice is grown in Asia, Africa, and Latin America on nearly 10 million hectares, making up 17% of the total rice grown worldwide (99). However, it is the dominant type of rice culture in portions of Africa and Latin America. Rice blast is particularly serious on rice grown in upland ecosystems, due to increased susceptibility to blast by plastic-grown under non-flooded conditions (11,118). In the upland ecosystems, rice blast is controlled primarily through the planting of resistant cultivars and cultural practices, both in the avoidance of resistant *M. grisea* and planting early in the season (11-13,149). Fungicides are also employed for the control of rice blast, but due to their relatively high cost they are practical only in more industrialized areas such as Brazil (99).

As observed for the reduction of yield of rice, typically Oryza sativa and Oryza glaberrima, studies in highly weathered soils and various parts of the world have shown that in lowland rice production brought about by heavy natural rainfall (117,118). Among the elements deficient in these soils is silicon (Si), which has been shown to be essential for maximum growth and yield of a number of plant species including O. sativa (97,98). Silicon has been reported to reduce shading of seeds in rice and increase the number of tillers, panicles per area harvested and 1000 grain (as well as increase 1000 grain weight) (17,100). Silicon is also known to alleviate several stresses, such as those caused by Al and Mn, and reduce the severity of important diseases of rice such as blast, brown spot, caused by *Coellobolus oryzae* (pre & Karsten) (in its) Dreder, or Dactyl, sheath blight, caused by *Thryothecium oryzae* (Fried) Dreder, stem rot caused by *Magnaporthe oryzae* (Coff), and leaf sheath, caused by *Magnaporthe oryzae* (Fried) Dreder (91-93,97-98,119,120). Increased levels of Si in the rice plant are associated with decreased levels of grain disarticulation or harvest loss (117,120,121). The apparent benefit of fertilization with Si on (though in some cases increased water use efficiency, lowered rates of transpiration, greater efficiency in light use, enhanced uptake of phosphorus, and increased plant strength (97,98,117,120). The role of Si in reducing plant diseases is not clearly understood. In the case of rice blast, Si may act to block penetration by *M. grisea* through cuticular or the lack of susceptible complexes in formation of a physical barrier of hydrated silica beneath the outside of the epidermis (92,100,101). Silicon may play a role in pathogenesis related host defenses as well. Studies on the blight-resistant and blight, *Pyricularia oryzae* and *Pyricularia grisea*, and *Sporisorium oryzae* and *Sporisorium pathogenicum* are evidence that silicon plants exposed with the reduction of Si based compounds reduced plant

defense elements, such as lignins, phenolics, proteinases, and chitinases at the sites of invasion by fungal pathogens (24,26,28).

Differential accumulation of Si has been documented among rice cultivars grown under flooded and upland conditions (26,33). Wenders (33) found significant differences in yield, incidence of neck blast and leaf blast, and grain development among eight genotypes of rice fertilized with Si or iron upland rice fields in southern Africa, but could not find differences in these variables between genotypes.

The purpose of this study was to investigate the role of Si in enhancing host resistance to disease by evaluating the response of resistant, partially resistant, and susceptible cultivars of rice, grown under upland conditions in eastern Colombia, to neck blast and leaf blast following the addition of Si at three rates. Additionally, partially resistant and susceptible cultivars were evaluated to determine if fertilization with Si would increase resistance to leaf and neck blast to levels comparable to blast-resistant cultivars, reduce exposure yield and milling quality. The effects of fertilization methods were also evaluated as components of yield and grain development.

Materials and Methods

Location. Experiments were conducted in 1996 at two locations situated approximately 38 km east of Villavieja, Colombia. The first location was the dense Roca research station, maintained by the Centro Internacional de Agricultura Tropical (CIAT) as a rice breeding nursery. The soil type was an Inceptisol with the following characteristics: pH 4.3, cation exchange capacity (CEC) 3.11, 18.2% Al saturation, and approximately 4 ppm plant-available Si . The second site was located approximately 5 km west of Santa Rosa in the Insular-Colombiana Agroparrucera's (ICA)-La Libertad

experiment station. The soil type (Dowry) at the La Libertad site was representative of upland conditions in the savanna of Colombia. Soil pH was 4.7 and less than 1 ppm plant-available nitrate was determined to be present. The CEC was 139 and the Al saturation was 79%.

Experimental design and layout. The experimental designs at both locations were split-plot with three replications. Whole plots were 56 m², expressed as the rate of fertilizer rate applied per plot at various rates (T) per hectare, and sub-plots were 16 m² replicates. Wallastonite was applied 3 days before planting at 0, 3.5, and 8 T ha⁻¹, corresponding to 0, 100, and 200 kg of elemental Si ha⁻¹. The most tolerant *Oryza* Lines 1 (fully resistant), Lines 2 (partially tolerant), and *Oryza* 3 (fully susceptible) were planted at Santa Rosa, while *Oryza* Sabana 10 (fully resistant), Line 2 (partially tolerant) and BLZ 146 (just susceptible) were planted at La Libertad. The cultivars planted at La Libertad were best suited locally for the savanna ecosystem, and were thus chosen for that location instead of the cultivars planted at Santa Rosa. Whole plots were 3 × 8.26 m, and were subdivided into three 3 × 3.33 m sub-plots (3.2 rows per sub-plot). Spacing between plots in each block was 3 m and spacing between blocks was 2 m. A border consisting of two rows of the susceptible cultivar (susceptible to each test) was placed around the entire experimental area, with spacing of 3 m between experimental plots and the border rows.

Soil preparation and planting. Dolomite limestone (CaCO₃/Mg) was incorporated into the soil approximately 20 days prior to planting at both locations. At Santa Rosa, phosphorus, potassium, magnesium sulfate, and boron were applied incorporated at rates of 60, 20, 40, and 3.4 kg/ha⁻¹, respectively. Phosphorus (100 kg/ha⁻¹),

potassium (44 kg ha^{-1}) and zinc sulfate (20 kg ha^{-1}) were incorporated prior to planting into each plot at La Libertad. Sulfur, in the form of elemental (CaSO_4) (B.T. Vanderhoff, Norwalk CT) was broadcast according to rate by hand and incorporated prior to planting with a harrow mounted disk. Agricultural lime (CaCO_3) was applied to those plots treated with 2.0 T of calcium sulfate ha^{-1} and those not treated with elemental to adjust the Ca level to that of the treatment with 1 T of calcium sulfate ha^{-1} (average). All zinc sulfate was disk-incorporated at a rate of 20 kg ha^{-1} to a depth of 7.5 cm . Row spacing was 0.76 m . Planting date at Santa Rosa was 21 May; however, the test was destroyed due to heavy rain following planting and had to be re-seeded on 14 June. At La Libertad, plots were planted on 24 May.

At both locations, nitrogen was applied at 17, 30, 50 and 70 days after planting at rates of 1.7, 3.0, 5.0, and 44 kg ha^{-1} respectively. The Santa Rosa one received an additional 30 kg of potassium at 30 DAP while 45 kg of potassium ha^{-1} and 25 kg of magnesium sulfate ha^{-1} magnesium sulfate were applied at 30 DAP at La Libertad.

Fungus and herbicide were applied at their recommended rates for control of weeds and for stem-borer defoliation and dipteris were applied as needed for insect control.

Stem collection and analysis. Prior to the appearance of disease, five plants per sub-plot were tagged at the base of the main tiller with a 2.5 cm section of plastic tubing of 2.5 cm diameter that had been coated with fluorescent paint. At each location, severity of leaf blight for each cultivar was evaluated at a single date (Table 5) using maximum rating by visually estimating the percent diseased leaf area of each leaf of the five marked tillers. Severity of leaf rust was evaluated by splashing five non-rust-free ears

Table 5.8. Degree of evaluation of leaf litter and leaf wood for three subunits of forest in (Azuero Forest and La Libertad), Colombia in 1994

| | Degree of Evaluation | |
|-------------|----------------------|-------------|
| | Azuero Forest | La Libertad |
| Leaf litter | 8/20/94 | 7/10/94 |
| Leaf wood | 8/20/94 | 8/13/94 |

whiplast and randomly choosing five leaves from the middle portion of the plant canopy. Severity was rated as the percent diseased leaf area of the five selected leaves. Leaf senescence dates for each crop are listed in Table 1.1. Severity of neck blast was estimated on 20 randomly selected panicles per plot. Values for overall severity of neck blast were calculated by the following formula (24):

$$\text{severity}(\%) = (10 \times N_1) + (20 \times N_2) + (40 \times N_3) + (70 \times N_4) + (100 \times N_5) / 100 \text{ panicles}$$

The numbers $N_1 - N_5$ represent the number of panicles with leaves of 1, 2, 3, 4, or 5 scored as such using a crop 0-5 scale. These values were then multiplied by a weighting factor. The scale, developed by the International Rice Research Institute is as follows: 0= no symptoms, 1=lesions on peduncle and branches, 2=lesions on branches and panicle base, 3=lesions partly surrounding base of panicle, 4=lesions completely surrounding base of panicle, with greater than 50% of grains filled, and 5=lesions completely surrounding base of panicle, with fewer than 50% of grains filled (24). Incidence was determined from the same 10 panicles and was scored as the number of panicles with symptom types 3-5 (24). Neck blast was evaluated at growth stage 9, or the mature grain stage (24). Evaluation dates for neck blast varied according to reference (Table 3.2).

Sub-plots were harvested by hand on 18 September at La Libertad, and on 22 October at Santa Rosa. A 3 × 3 m section was marked at each sub-plot using a white frame, and only those tillers within the frame were cut. A 1 × 1 m frame was placed within the 3 × 3 m framed area and all tillers in the 1-m² area were cut prior to harvesting the larger area. Yields of rough rice (kg/ha²) were determined from grain harvested in the 1 m² portion of each sub-plot and were adjusted to reflect a 12% moisture content,

Table 4.2 Dates of evaluations of seed blight made at Santa Rosa and La Libertad, Colombia for resistant, partially resistant, and susceptible rice cultivars in 1976

| Cultivar | Type | Date of Evaluation | |
|-----------------|---------------------|--------------------|-------------|
| | | Santa Rosa | La Libertad |
| Oryza Litorea 5 | resistant | 10/18/76 | — |
| Lata 2 | partially resistant | 10/16/76 | — |
| Oryza 1 | susceptible | 10/16/76 | — |
| Oryza Sabana 10 | resistant | — | 9/16/76 |
| Lata 2 | partially resistant | — | 9/17/76 |
| BLAT 141 | susceptible | — | 10/6/76 |

Material harvested from the 1-m² area was used to determine the number of panicles³, number and weight of grains per 25 panicles and thousand-grain weight. Grain discolouration was estimated using the 0-4 peduncal scale, where 0/ grains with no discolouration and 4/ grains completely discoloured (14).

Grilling quality of rough rice was determined by placing a 125-g sample from each sub-plot in a de-buller (H.T. McGill and Co., Houston, TX). Brown rice yields were estimated, followed by further milling to remove the husk layer from grains. Total oil yields were determined after which samples were sorted using a Carter-Day Model XT 3-shakegrader (Carter-Day Inc., Minneapolis, MN). Samples were divided into two classes, whole and broken, and the percentage of grains falling into each class was calculated by dividing the weight of grains in a given class by the sample size. All sample weights were adjusted to 12% moisture content.

Leaf tissue samples were collected at the time of evaluation for leaf blight severity at both locations to determine % concentration of plants in uninfected and % infected plots. Additionally, roughly 500 g of stem tissue were collected and dried at harvest time. Dried tissue was ground to-powder through a 40-mesh screen using a Thomas Wiley mill (Thomas Scientific, Swedesboro, NJ). Nitrogen content of tissue samples was determined by first digesting 0.1 g of dried tissue as described by Elmer and Snyder (18) followed by automated colorimetric analysis. Results obtained from automated colorimetric analysis, expressed as absorbance units (au⁴), were converted to percentage reflecting nitrogen (g/g) of 10 per kg of plant tissue.

All data collected were analyzed by analysis of variance (ANOVA), correlation, and regression procedures where appropriate with SAS version 6.12 (SAS Institute, Cary NC).

Results

Leaf blight. The interaction between rate of S₂ (whole plot) and row number (sub-plot) was significant in both Santa Rosa and La Libertad, requiring the analysis of each main effect as fixed levels of the remaining effect ($P < 0.05$) (Fig. 3-1). Overall severity of leaf blight was greater at Santa Rosa than at La Libertad (Fig. 3-1). At Santa Rosa, Oryza Linceo 5 (blat resistant), Linceo 2 (partially blat resistant), and Oryza 1 (blat susceptible) all differed significantly from each other in level of leaf blight severity when no S₂ was applied ($P < 0.05$). Oryza Linceo 2 had less than 1% diseased leaf area, while Linceo 2 and Oryza 1 had 1-6% and 5-9% diseased leaf area, respectively (Fig. 3-1a). At both 500 and 1000 kg of S₂ ha⁻¹, Oryza Linceo 2 and Linceo 2 did not differ significantly in percent diseased leaf area ($P > 0.05$), whereas at 1% and 1-6% DLA, Oryza 1 showed higher severity of leaf blight than the other two cultivars ($P < 0.05$) (Fig. 3-1a). The application of S₂ at 500 and 1000 kg ha⁻¹ significantly reduced severity of leaf blight on Linceo 2 and Oryza 1; however, no significant reduction was seen in disease severity, regardless of rate, for the blat resistant cultivar Oryza Linceo 5 (Fig. 3-1a). For both Linceo 2 and Oryza 1, the relationship between rate of S₂ and disease severity was significant ($P < 0.05$) and linear, with severity of disease decreasing as rate of S₂ increased. Severity of leaf blight was 50 and 73% lower at the highest rate of S₂ than when no-S₂ had been applied for both Linceo 2 and Oryza 1, respectively (Fig. 3-1a).

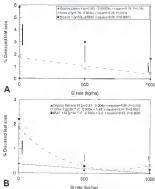


Figure 1. Relationship between the coverage of leaf flat area and LA applied at 0, 500, and 1000 kg/ha for resistant, partially resistant, and susceptible cultivars plotted as: A) *Le Bonheur* and B) *Colossal* (Colossal in 1999). Each point represents mean (n=3) values of percent dissected leaf area for each cultivar. Vertical bars represent values of least significant difference ($P < 0.05$) for the comparison of means at a given rate of LA.

To determine if the application of Zn to blast-susceptible cultivars could raise the level of resistance to that of partially resistant or resistant cultivars, means of selected cultivars (6 combinations) were compared by single degree of freedom contrasts (Fig. 3.1a, Table 3.1). The combination of Oryza 1 plus either 500 or 1000 kg of Zn ha⁻¹ did not reduce the severity of leaf blight to the same statistical level as that for the resistant cultivar, Oryza Sabana 3 ($P < 0.05$), however, the severity of leaf blight did not differ significantly between the combination of Oryza 1 plus 1000 kg of Zn ha⁻¹ and the partially resistant Lines 2 resistant Zn (P=0.04) (Fig. 3.1a, Table 3.1). No significant differences in severity of leaf blight were observed between Oryza Sabana 3 without Zn and Lines 1 plus 500 or 1000 kg of Zn ha⁻¹ ($P > 0.04$) (Fig. 3.1a, Table 3.1).

At La Libertad, highest leaf blight severity was observed for BLAT 143 (blast-susceptible) and Lines 2 (partially blast-resistant) at the 5 kg ha⁻¹ rate of Zn (Fig. 3.1b). Where Zn was not applied, the severity of blight was not significantly different between BLAT 143 and Lines 2 ($P > 0.05$). Oryza Sabana 18 (blast-resistant) had significantly lower leaf blight severity than either BLAT 143 or Lines 2 (Fig. 3.1b) without Zn (Fig. 3.1b) ($P < 0.05$). At 1000 kg of Zn ha⁻¹, the severity of leaf blight did not differ significantly among the three cultivars (Fig. 3.1b). Oryza Sabana 18 and BLAT 143 did not differ in leaf blight severity at 1000 kg of Zn ha⁻¹. Rate of Zn significantly influenced severity of leaf blight for each cultivar at La Libertad (Fig. 3.1b). A linear decrease in blast severity of Y330 was noted for Oryza Sabana 18 when the rate of Zn was increased from 5 to 1000 kg ha⁻¹ ($P < 0.04$) (Fig. 3.1b). The relationship between the rate of Zn and severity of blight was found to be quadratic for Lines 2 and BLAT 143 and for both cultivars, blast severity decreased by 83-92% as Zn rate increased ($P < 0.005$) (Fig. 3.1b).

Table 8.1. Effects of Se addition on leaf/fruit severity on three cultivars of rice at Santa Rosa and La Libertad, Colombia (1998). Comparisons represent single degree of freedom contrasts between mean values of percent leaf area with disease for selected Se cultivar combinations (see Figs. 8.1-8.2).

| Location and contrast (Cultivar and Se rate) | Leaf/fruit | |
|---|------------|-------|
| | F value | P < P |
| Santa Rosa | | |
| Oryza 1 (500) vs. O. Llanos 5 ^a (0) ^a | 25.5 | 0.000 |
| Oryza 1 (500) vs. O. Llanos 5 (0) | 6.74 | 0.01 |
| Oryza 1 (500) vs. Llanos 2 (0) | 3.80 | 0.06 |
| Oryza 1 (1000 kg) vs. Llanos 2 (0) | 0.07 | 0.79 |
| Llanos 2 (500) vs. O. Llanos 5 (0) | 1.09 | 0.31 |
| Llanos 2 (1000) vs. O. Llanos 5 (0-10) | 0.46 | 0.50 |
| La Libertad | | |
| BLAT 140 (500) vs. O. Sabana 10 ^b (0) | 0.41 | 0.53 |
| BLAT 140 (1000) vs. O. Sabana 10 (0) | 2.95 | 0.10 |
| BLAT 140 (500) vs. Llanos 2 (0) | 139.6 | 0.000 |
| BLAT 140 (1000) vs. Llanos 2 (0) | 143.1 | 0.000 |
| Llanos 2 (500) vs. O. Sabana 10 (0) | 8.89 | 0.00 |
| Llanos 2 (1000) vs. O. Sabana 10 (0) | 8.87 | 0.00 |

^aO. Llanos 3=Oryza Llanos 3

^bNumbers in parentheses are rates of Se in kg ha⁻¹

^cO. Sabana 10=Oryza Sabana 10

At La Libertad. S_0 applied at 500 and 1000 kg ha^{-1} reduced the severity of leaf blight on the blight susceptible cultivar BOAT 140 and the partially blight resistant cultivar Loma 2 to the same statistical level as Oryza Sativa 10 without S_0 ($P < 0.05$) (Fig. 3.1b; Table 3.2). Severity of leaf blight was lower for BOAT 140 plus 500 and 1000 kg a.l.h^{-1} as compared to Loma 2 without S_0 ($\text{S}_0 \text{ kg ha}^{-1}$) (Fig. 3.1b; Table 3.2).

Leaf mold. At both locations, no significant interaction was present between whole plot and subplot effects ($P < 0.05$) (Fig. 3.3a). At Santa Rosa, severity of leaf mold was generally greater than at La Libertad, and was not significantly different among cultivars ($P < 0.05$) (Fig. 3.3a). However, a significant linear relationship was found between the rate of S_0 and the severity of leaf mold ($P < 0.05$) (Fig. 3.3a). For all cultivars, an increase in the rate of S_0 (from 0 up to 1000 kg ha^{-1}) resulted in a 42% decrease in the severity of leaf mold.

Leaf mold was greater at La Libertad on Oryza Sativa 10 when compared to Loma 2 and BOAT 140 for 0 kg a.l.h^{-1} and 500 kg a.l.h^{-1} , respectively ($P < 0.05$). At the 1000 kg ha^{-1} rate of S_0 , the severity of leaf mold was greater on Oryza Sativa 10 than on Loma 2 or BOAT 140 (Fig. 3.3a). The severity of leaf mold, averaged across all cultivars, decreased linearly by 42% as the rate of S_0 increased from 0 to 1000 kg ha^{-1} ($P < 0.05$) (Fig. 3.3a).

Dark blight. The interaction between whole plot and subplot was significant ($P < 0.05$). Therefore, means for each effect (rate of S_0 and cultivar) are reported at fixed levels of alternative effects. Levels of both incidence and severity of dark blight were higher at the Santa Rosa site than at La Libertad (Figs. 3.3.3-4). At Santa Rosa, the main rate of S_0 , dark blight incidence and severity were significantly different between cultivars

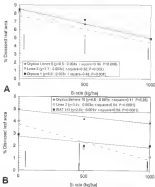


Figure 5.3. Relationship between the severity of leaf rust and Zn application at 500 and 1000 kg/ha for three cultivars planted at A) Barranquilla and B) La Loberia, Colombia in 1994. Each point represents values (n=7) of percent diseased leaf area for each cultivar. Vertical bars are values of least significant differences (P=0.05) for comparison of means at a given rate of Zn.

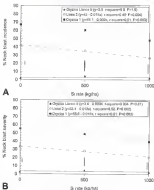


Figure 1.1: Relationship between (A) incidence and (B) severity of root blight of rice and Bt applied or B (500-1000 kg/ha) for resistant, partially resistant, and susceptible cottons planted in Santa Rosa, California in 1956. Black points represent the mean values (%) of incidence or severity for each cotton. Horizontal lines represent values of least significant difference ($P=0.05$) for comparisons between means of a given rate of Bt.

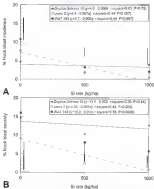


Figure 5-4. Relationship between the Aq/acid-insoluble and Bq/acid-soluble coverage of seeds treated with urea and Si applied at 0, 500, or 1000 kg/ha for the varieties partially resistant and susceptible to smut planted at La Libertad, Colombia in 1994. Each point represents mean values (\pm SE) of incidence or severity for each treatment. Vertical bars represent values of least significant difference ($p=0.05$) for comparisons between means at a given rate of Si.

Oryzae Lines 3, Lines 2, and Oryzae 1 ($P < 0.05$) (Fig. 3.3). Levels of neck blast incidence and severity observed corresponded to each cultivar's level of resistance indicated by *MR* genes. Severity of neck blast was 30–80% lower than incidence of disease on Lines 2 and Oryzae 1 (Fig. 3.3). Salinity rate had a significant effect on incidence and severity of neck blast for Lines 2 and Oryzae 1 ($P < 0.05$) (Fig. 3.3). Incidence and severity remained between 3–7% for Oryzae Lines 3 and did not change as the rate of Na increased. For Lines 2 and Oryzae 1, both severity and incidence of neck blast decreased 27 and 23%, respectively, as the rate of Na increased from 0 to 1000 kg ha^{-1} (Fig. 3.3).

At Santa Rosa, the addition of Na at 500 and 1000 kg ha^{-1} did not give resistance to neck blast for either Lines 2 or Oryzae 1 as levels equivalent to the resistance expressed by the blast resistant cultivar Oryzae Lines 2 without Na (Fig. 3.3, Table 3.4). Lines 2 and Oryzae 1 had significantly higher neck blast severity and incidence at 500 and $1000 \text{ kg of Na ha}^{-1}$ as compared to the blast resistant control ($P < 0.05$), however, the addition of $1000 \text{ kg of Na ha}^{-1}$ reduced incidence and severity of neck blast on Oryzae 1 as effectively as the partially blast-resistant Lines 2 without Na (Fig. 3.3, Table 3.4).

At La Libertad, there were no significant differences in incidence of neck blast between Oryzae/Salinas 36, Lines 2, and BAF 140 at all rates of Na , although, generally, incidence on each cultivar reflected the level of host resistance of each cultivar ($P < 0.05$) (Fig. 3.4). Partially resistant and susceptible cultivars had less disease severity than the resistant cultivar at increased rates of Na . At the 8 kg ha^{-1} rate of Na , no differences in neck blast severity were noted between any cultivars ($P < 0.05$); however, at 500 and 1000 kg ha^{-1} , the partially blast-resistant cultivar Lines 2 had 60–71.8% lower

Table 8a. Effects of % air moisture and severity of rock blight on first-colivores of fish at Santa Rosa and La Libertad. Comparisons represent single degree-of-freedom contrasts between mean percent values of incidence or severity of rock blight for selected Se-colivore combinations from Figs. 3.2.3.4.

| Location and resistant (C) (river and N rate) | Rock blight | | | |
|---|-------------|--------|----------|--------|
| | Incidence | | Severity | |
| <i>Santa Rosa</i> | | | | |
| | F value | P > F | F value | P > F |
| Oryzias 1 (500) vs. O. Latesa 1 ^a (2) | 193.1 | 0.0001 | 207.1 | 0.0001 |
| Oryzias 1 (1000) vs. O. Latesa 1 (2) | 121.0 | 0.0003 | 131.5 | 0.0001 |
| Oryzias 1 (1000) vs. Latesa 2 (2) | 26.2 | 0.0008 | 34.0 | 0.0001 |
| Oryzias 1 (1000) vs. Latesa 3 (2) | 2.34 | 0.14 | 3.02 | 0.09 |
| Latesa 2 (500) vs. O. Latesa 1 (2) | 62.8 | 0.0008 | 62.1 | 0.0003 |
| Latesa 2 (1000) vs. O. Latesa 1 (2) | 14.1 | 0.0001 | 30.8 | 0.0001 |
| <i>La Libertad</i> | | | | |
| BLAT 141 (500) vs. O. Salinas 1 ^b (2) | 0.48 | 0.49 | 0.11 | 0.73 |
| BLAT 141 (1000) vs. O. Salinas 1 ^b (2) | 1.46 | 0.23 | 14.7 | 0.0006 |
| BLAT 143 (500) vs. Latesa 2 (2) | 1.41 | 0.09 | 0.24 | 0.62 |
| BLAT 143 (1000) vs. Latesa 2 (2) | 1.83 | 0.08 | 2.18 | 0.15 |
| Latesa 2 (500) vs. O. Salinas 1 ^b (2) | 1.94 | 0.07 | 27.2 | 0.0001 |
| Latesa 2 (1000) vs. O. Salinas 1 ^b (2) | 3.43 | 0.07 | 10.8 | 0.0001 |

^aO. Latesa 2=Oryzias Latesa 1

^bNumbers in parentheses are rates of % air kg ha⁻¹

^cO. Salinas 10=Oryzias Salinas 10

severity ranges than *Oryza Sativa* H-9 or BLAT 143 (Fig. 3-4b). Severity of neck blast was significantly reduced by 50%-on BLAT 143 at 1000 kg of Zn ha^{-1} as compared to *Oryza Sativa* H-9 at the same rate (P<0.05) (Fig. 3-4b). No significant linear response was found to exist between Zn rate and either incidence or severity of neck blast on *Oryza Sativa* H-9 (P>0.05) (Fig. 3-4c). The response by BLAT 143 and Lines 3 to resistance with Zn was significant (P<0.05) and linear. Incidence of neck blast decreased by 81 and 55%, respectively, in BLAT 143 and Lines 3 when the rate of Zn increased from 0 to 1000 kg ha^{-1} (Fig. 3-4c). Severity of neck blast was reduced 63 and 55% on these cultivars at 1000 kg of Zn ha^{-1} as compared to 0 kg ha^{-1} (Fig. 3-4b).

Incidence of neck blast on BLAT 143 (100% susceptible) treated with 300 and 1000 kg of Zn ha^{-1} was reduced to levels not significantly different from *Oryza Sativa* H-9 without Zn (P>0.05), as determined by single degree of freedom contrasts (Fig. 3-4, Table 3-4). Lines 3 did not differ significantly in incidence of neck blast at 300 kg of Zn ha^{-1} when compared to *Oryza Sativa* H-9 without Zn, and had significantly lower incidence than *Oryza Sativa* H-9 without Zn when treated with 1000 kg ha^{-1} (P<0.05) (Fig. 3-4, Table 3-4). Neck blast severity was lower on BLAT 143 and Lines 3 treated with 300 and 1000 kg ha^{-1} Zn as compared to *Oryza Sativa* H-9 without Zn (P<0.05) (Fig. 3-4, Table 3-4).

Yield, grain quality, and components of yield. The association between rate of Zn and cultivars is related to grain yield, milling quality, grain-huskiness, yield components (number of panicles per m^2 , number of grains per 25 panicles, grain weight per 25 panicles, and thousand grain weight), and Zn content of rice straw (not test

significant ($P < 0.05$), which allowed the presentation of means by means that for these factors at both Santa Rosa and La Libertad.

Yields for each cultivar planted at Santa Rosa, by rate of S, are illustrated in Fig. 3.5. In general, yields of rough rice were higher for those cultivars planted at Santa Rosa than for those at La Libertad. Oryzasa-Limon 3 (regardless of rate of S) had higher yields than Limon 3 ($P < 0.05$). At 1000 kg of S/ha, yields of Oryzasa 1 and Oryzasa-Limon 3 did not differ significantly ($P > 0.05$) (Fig. 3.5a). Rough rice yields were, on average, 22% higher for the fully resistant cultivar Oryzasa-Limon 3 than for the susceptible Oryzasa 1, and 17% higher than those of the partially fully resistant Limon 3 (Fig. 3.5a). Yield of rough rice did not differ significantly between Limon 3 and Oryzasa 1 ($P > 0.05$). For all cultivars except Oryzasa 1, the relationship between S rate and yield was significantly linear ($P < 0.05$). When the rate of S was increased from 0 to 1000 kg ha⁻¹, yield increased by 30% for Oryzasa-Limon 3 and Limon 3 (Fig. 3.5a).

At La Libertad, yield of rough rice was significantly influenced ($P < 0.05$) by both S rate and cultivar (Fig. 3.5b). Limon 3 produced the highest yield, 3800 kg ha⁻¹ when averaged across all rates of S, followed by SPAT 143 and Oryzasa-Salmon 15. The relationship between S rate and yield for all cultivars was significant ($P < 0.05$) and linear (Fig. 3.5b). Yield increased for all cultivars by 42% when the S rate changed from 0 to 1000 kg ha⁻¹.

Fertilization with S at 500 and 1000 kg ha⁻¹ raised yields of Oryzasa 1 to levels comparable to Oryzasa-Limon 3 (without S). Oryzasa 1, treated with 500 and 1000 kg ha⁻¹ S, did not differ significantly in yield of rough rice as compared to Oryzasa-Limon 3 without S ($P > 0.05$) (Fig. 3.5a, Table 3.3). Yields of Oryzasa 1 at 500 and 1000 kg of S

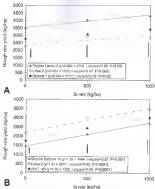


Figure 5.6: Rough rice yield of rough rice and Si applied at 0, 500 and 1000 kg/ha for two rice cultivars planted at A) Sasa Roza and B) La Libertad (Colombia in 1994). Each plot represents values (P=0.05) of yield of rough rice for each cultivar. Vertical bars are values of least significant difference (P=0.05) for comparisons of means at a given rate of Si.

Table 5.9 Effects of Se on yield of rough rice on three cultivars at Santa Rosa and La Libertad. Comparisons represent single degrees of freedom contrasts between mean values of percent leaf area with disease for selected Se-cultivar combinations from Fig. 5.3

| Location and contrast (Cultivar and Se rate) | Rough rice yield | |
|--|------------------|--------------------|
| | F value | P ^a > F |
| Santa Rosa | | |
| Ceylan 1 (500) vs. Q. Llanos 2 (0) | 3.33 | 0.07 |
| Ceylan 1 (1000) vs. Q. Llanos 2 (0) | 8.60 | 0.01 |
| Ceylan 1 (500) vs. Llanos 2 (0) | 2.11 | 0.16 |
| Ceylan 1 (1000) vs. Llanos 2 (0) | 3.33 | 0.08 |
| Llanos 2 (500) vs. Q. Llanos 2 (0) | 5.03 | 0.03 |
| Llanos 2 (1000) vs. Q. Llanos 2 (0) | 10.4 | 0.003 |
| La Libertad | | |
| Q. Salinas 10 (500) vs. Llanos 2 (0) | 9.63 | 0.01 |
| Q. Salinas 10 (1000) vs. Llanos 2 (0) | 5.43 | 0.03 |
| Q. Salinas 10 (500) vs. BLAT 143 (0) | 16.4 | 0.0001 |
| Q. Salinas 10 (1000) vs. BLAT 143 (0) | 40.3 | 0.0001 |
| BLAT 143 (500) vs. Llanos 2 (0) | 1.33 | 0.26 |
| BLAT 143 (1000) vs. Llanos 2 (0) | 12.5 | 0.001 |

^aQ. Llanos 2-Ceylan 1; Llanos 2

^bNumbers in parentheses are rates of Se in kg ha⁻¹

^cQ. Salinas 10-Ceylan 1; Salinas 10

ha⁻¹ were not significantly different from those of Lotus 2 without S₂ (P>0.05).

Regardless of the amount of S₂ added, yields of Lotus 2 were always lower than those of Oryzopsis (Lotus 3 without S₂).

At La Libertad, yields of rough rice were greater for the partially blast-resistant cultivar Lotus 2 at 0 and 500 kg of S₂ ha⁻¹ than for the blast resistant Oryzopolis 18 or the blast-susceptible IRAT 143. Lotus 2, therefore, was used as a standard for comparison to determine the ability of S₂ to raise yields of the remaining two cultivars. The addition of 1000 kg S₂ to Oryzopsis Sakana 18 and IRAT 143 resulted in higher (P<0.05) yields than Lotus 2 without S₂ (Fig. 3.3a, Table 3.2).

Milling quality of grain harvested from cultivars planted at Santa Rosa was superior to that of grain from the cultivars planted at La Libertad (Table 3.4). At Santa Rosa, grain samples of Oryzopsis Lotus 3, at all rates of S₂, had better milling quality than Lotus 2 and Oryzopsis 1 (P<0.05). Samples of rough rice for Oryzopsis Lotus 3 had a greater percentage of whole grains (head rice) and a lower percentage of broken grains than Lotus 2 or Oryzopsis 1 (Table 3.4). No significant differences in percentages of whole or broken grain were found between Lotus 2 and Oryzopsis 1 (P>0.05) (Table 3.4). For all cultivars, the percentage of whole grains increased linearly as the rate of S₂ increased (Fig. 3.4a). At 1000 kg of S₂ ha⁻¹, 30% more head rice was recovered than at 0 kg ha⁻¹. The percentage of broken grains for each cultivar decreased linearly with increasing rate of S₂ (Fig. 3.4a). At 1000 kg of S₂ ha⁻¹, fewer (P<0.05) broken grains were recovered from Oryzopsis Lotus 3, Lotus 2, and Oryzopsis 1 as compared to 0 kg of S₂ ha⁻¹. As the rate of S₂ increased from 0 to 1000 kg ha⁻¹, the percentage of broken grains decreased by 1.5% (Fig. 3.4b).

Table 8.4 Yield and grain quality for resistant, partially resistant, and susceptible cultivars of maize at Santa Rosa and La Libertad, Colombia (1996). Means are a range across site of 5 to 10 each cultivar.

| Location and cultivar | Percent | Percent | Discoloration |
|--------------------------|------------------------|--------------------------|---------------------|
| | Head Rice ^a | Broken Rice ^a | Rating ^b |
| <i>Santa Rosa</i> | | | |
| Oryza Limón 3 | 53.5 a | 56.1 b | 2.0 a |
| Limón 2 | 57.6 b | 50.8 a | 2.1 a |
| Oryza 1 | 58.8 b | 52.9 a | 2.0 a |
| <i>La Libertad</i> | | | |
| Oryza Sabana 18 | 55.6 b | 48.0 b | 1.3 a |
| Limón 2 | 58.1 a | 50.1 a | 1.8 a |
| BOAT 180 | 57.2 a | 46.7 a | 3.0 a |

^aMean percentage of grains in two classes, head rice (whole grains) and broken, from a 120g sample, taken across all 50 rows and replicated four times. Means followed by the same letter within each 50 grouping do not differ significantly ($P=0.05$) by Fisher's protected LSD test.

^bGrain discoloration, rating of rough rice, rated on a 5-6 potential scale, where 0=clean grains and 5=completely discolored grains. Data shown are means taken across all 50 rows and replicated four times. Means followed by the same letter within each 50 grouping do not differ significantly (Santa Rosa: $P=0.10$, La Libertad: $P=0.05$) by Fisher's protected LSD test.

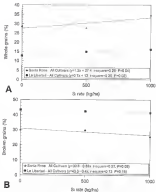


Figure 1a. Relationship between (A) percentage of whole grains and (B) percentage of broken grains (milling quality) and Zn applied only 500 and 1000 kg/ha. Zn concentrations were either placed at Santa Rosa and La Libertad, Colombia in 2016. Each point represents values (y - x) of percentages of whole or broken grains averaged across all cultures.

At La Libertad, milking quality was significantly different between Oryzias Sabana 18, Lanes 2, and BAT 143 ($P < 0.05$) (Table 3-4). The highest percentage of head rice, as well as the lowest percentage of broken grains, was recovered from Lanes 2. Oryzias Sabana 19 and BAT 143 had 55 and 62% lower whole grains as compared to Lanes 2 (Table 3-4). Oryzias Sabana 19 and BAT 143 had 28 and 33% more grains, respectively, in the broken-rice class than Lanes 2 (Table 3-4). The percentage of whole grains, for all cultivars, increased by 15% when the rate of Ss increased from 5 to 1000 kg ha⁻¹ ($P < 0.05$) (Fig. 3-4a). No significant differences in the percentage of broken grains for Oryzias Sabana 18, Lanes 2, or BAT 143 were found between the 5, 200, and 1000 kg ha⁻¹ rates of Ss (Fig. 3-4b).

Readings of grain discolouration from samples of rough rice from Santa Rosa and La Libertad are presented by rate of Ss and cultivar and as averages across both locations (Fig. 3-5a, Table 3-5). Grain discolouration did not differ significantly between cultivars at either location ($P > 0.05$) (Table 3-5). The rate of Ss had a significant effect on grain discolouration at both locations ($P < 0.05$) (Fig. 3-5b). Grain discolouration, averaged across all cultivars, decreased linearly as the rate of Ss increased at Santa Rosa and La Libertad. At 1000 kg of Ss ha⁻¹, grain discolouration was reduced by 25% and 30% over the amount at Santa Rosa and La Libertad, respectively (Fig. 3-5b).

Components of yield were affected by rate of Ss and by cultivar at Santa Rosa and La Libertad. Regardless of the rate of Ss, the number of panicles per m² was greater for Oryzias Lanes 2 and Oryzias 1 than for Lanes 2 at Santa Rosa ($P < 0.05$) (Table 3-7). The number of filled grains per 15 panicles did not differ significantly among the three cultivars planted at Santa Rosa ($P > 0.05$), however, the weight of filled grains from

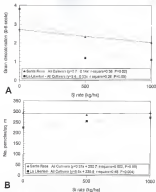


Figure 3.3. Relationship between (A) grain N concentration and (B) number of panicles m⁻² and N applied at 0, 500 and 1000 kg/ha for three cultivars of rice planted at Santa Rosa and La Libertad, Colombia in 2006. Each point represents values (or N) of grain N concentration or number of panicles (or yield) across all cultivars.

Table 3.7 Yield components for resistant, partially resistant, and susceptible cultivars of rice in Santa Rosa and La Libertad, Colombia in 1996. Means are averaged across rate of N in each column

| Location and cultivar | Plants/m ² | Filled grains 25 plants/m ² * | Vol. grains 25 plants/m ² (g) | 1000- grain wt. (g) |
|--------------------------------|-----------------------|---|---|------------------------|
| Santa Rosa | | | | |
| Ceylan Sabana 3 | 308.7 a ^c | 1027.0 a | 66.1 a | 29.9 a |
| Loma 3 | 248.4 b | 1219.6 a | 62.1 ab | 29.9 a |
| Ceylan 3 | 288.8 a | 1250.6 a | 68.1 b | 26.6 b |
| La Libertad^d | | | | |
| Ceylan Sabana 30 | 234.1 b | 1454.9 a | 63.3 b | 24.6 b |
| Loma 3 | 272.9 a | 1347.6 b | 66.2 a | 29.3 a |
| IRAT 145 | 341.0 b | 1398.0 a | 61.3 ab | 24.0 c |

*In each column, data are the means of 3 replications, averaged across all N rates. Means followed by the same letter do not differ significantly ($p < 0.05$) by Fisher's protected LSD.

Oryza/Linea 2 was significantly less than that of Oryza 1. Thousand-grain weight was lower for Oryza 1 than for either Oryza (Lines 1 or Linea 2) ($P < 0.05$). Rate of tiller out let had a significant linear effect on the number of panicles/m² for all cultivars at Santa Rosa (Fig. 3.7b). A significant linear relationship occurred between number of filled grains per 25 panicles and rate of tiller out let ($P < 0.05$) (Fig. 3.8). The number and weight of filled grains per 25 panicles increased by 1% for all cultivars at 1000 kg of tiller ha⁻¹ as compared to 8 kg ha⁻¹. Thousand-grain weight was not significantly different between cultivars for any rate of tiller out let at Santa Rosa (Fig. 3.9).

At La Libertad, across all rates of tiller out let, Linea 2 had more panicles per m² than Oryza Salinas 10 or IRAT 143 ($P < 0.05$). However, fewer filled grains per 25 panicles were collected from Linea 2 than from Oryza Salinas 10 or IRAT 143 ($P < 0.05$) (Table 3.7). A greater number of filled grains per 25 panicles was observed for Linea 2 and not IRAT 143 than for Oryza Salinas 10. Thousand-grain weights differed significantly between all cultivars at La Libertad ($P < 0.05$) (Table 3.7). Highest values of thousand-grain weight were recorded for Linea 2, which were less than Oryza Salinas 10 and IRAT 143, were 13% and 30% lower, respectively. At La Libertad, the number of panicles per m², number of filled grains per 25 panicles, weight of filled grains per 25 panicles, and thousand-grain weight had significant linear relationships with the rate of tiller out let ($P < 0.05$) (Figs 3.7a, 3.8 and 3.9). These components of yield increased by 18, 15–25 and 4%, respectively, as the rate of tiller out let was increased from 8 to 1200 kg ha⁻¹.

Grain content of plant tissue. Analysis of tiller content of leaf tissue collected after evaluation of leaf blast and of roots tissue collected before harvest showed that, at both Santa Rosa and La Libertad, there were no significant differences in the percentage

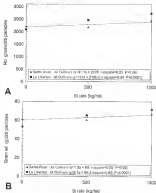


Figure 10. Relationship between (A) the number of total grasshopper parasites and (B) weight of total grasshopper parasites and the applied N rate (0, 500 and 1000 kg/ha) for three cultivars of rice (IR64, IR504 and IR64) grown in Santa Rosa and La Libertad, Colombia in 1996. Each point represents mean value (\pm SE) of grass number and weight averaged across all cultivars.



Figure 14-9 Relationship between fertilizer (kg/ha) and 1000 grain wt. (g) for three cultivars of rice planted at Santa Rosa and Le Uthai, Calicut, in 1994. Each point represents mean values ($n=3$) averaged across all cultivars.

of Si among cultivars ($P=0.03$) (Figs. 3 (b)–3 (c)). There was little difference in the amount of Si between leaf and stem tissue at Santa Rosa, however, stem tissue collected at La Libertad had roughly 10% less Si than leaf tissue, at each rate of Si for all cultivars (Figs. 3 (b)–3 (c)). At both locations, a significant linear relationship was found to exist between Si rate and the amount of Si present in leaf and stem tissue ($P<0.05$) (Figs. 3 (b)–3 (c)). At Santa Rosa, Si content of leaf and stem tissue increased by 17% and 27% respectively, as the rate of Si was increased from 0 to 1000 kg ha^{-1} (Fig. 3 (b)). The overall response by tissue to Si fertilisation at La Libertad was of a greater magnitude than at Santa Rosa. Soluble content of leaf and stem tissue increased by 17% when rate of Si was increased from 0 to 1000 kg ha^{-1} at La Libertad (Fig. 3 (c)). The soluble content of both leaf and stem tissue collected from plants that received no Si was 18–40% lower at La Libertad than at Santa Rosa (Figs. 3 (b)–3 (c)).

Correlation analysis. At Santa Rosa, yield of rough rice and the percentage of whole grains were positively correlated with the application of Si ($P<0.05$), while the percentage of broken grains was negatively correlated with Si (Table 3 (a)). A highly significant positive correlation was found between yield and Si at La Libertad ($P<0.0001$), however, milling quality was not correlated with Si . At both locations, the positive correlation between application of Si and Si content in leaf and stem tissue was highly significant ($P<0.0001$).

Correlations between leaf blast, leaf mild, and neck blast and variables such as yield and Si content of plant tissue varied by cultivar at both locations (Tables 3 (b) and 3 (c)). For the blast-resistant cultivar Oryza Lativa 5, the correlation between leaf blast and yield was not significant at Santa Rosa ($P=0.30$), however, a significant negative

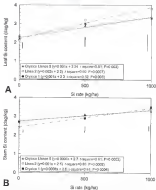


Figure 8-34: Relationship between Si content in A) leaf tissue and B) stem tissue and Si applied at 0, 500, 1000 kg/ha for maximum, partially maximum, and nonoptimal volumes of rice planted at Basin Base, California, in 1994. Data point represents mean values (\pm SE) of Si content for each cultivar. Vertical bars are reduced from significance difference ($P<0.05$) for comparisons of means at each rate of Si.

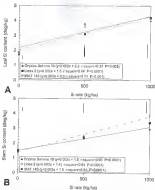


Figure 8-11 Relationship between Zn content in *Achillea* leaves and *Rumex crispus* stems with Zn applied at 0–1000 kg/ha for untreated, partially-treated, and inoculated cultures of root plantlets of *Linum catharticum* (Colombini, et al. 1994). Each point represents mean values for 50 of Zn content for each culture. Vertical bars represent standard errors of least-squares regression ($P < 0.05$) for comparison of means at each rate of Zn.

Table 3.6. Pearson correlation coefficients for rate of N vs. yield and grain quality of rice

| Site | Pearson correlation coefficients | | | | |
|-------------|----------------------------------|------------------------------|----------|-----------------------|--------|
| | Yield ^a | Milling quality ^b | | Thousand-grain weight | |
| | | % Head rice | % Broken | Local | Mean |
| Santa Rosa | 0.74 | 0.58 | -0.57 | 0.73 | 0.76 |
| Pach > (R) | 0.81 | 0.608 | -0.61 | 0.6921 | 0.6921 |
| n=13 | | | | | |
| La Libertad | 0.72 | 0.18 | -0.18 | 0.68 | 0.69 |
| Pach > (R) | 0.6981 | 0.25 | -0.2 | 0.6001 | 0.6001 |
| n=12 | | | | | |

^aN applied at 0, 500, and 1000 kg ha⁻¹

^bYield of rough rice (kg ha⁻¹) from 1st harvest, partially 1st harvest, and susceptible cultivars planted at Santa Rosa and La Libertad

^cPercentage of grain from a 100 g sample sorted into two classes, head rice (whole grain) or broken grain

Table 4.8 Pearson correlation-coefficients for leaf N_{area}, leaf N_{total}, biomass and severity of neck blight of rice vs. yield and grain N_{content}, by cultivar at Baka Baka

| Cultivar and Variable ^a | Yield ^b | | Leaf N _{Content} ^c | | Grain N _{Content} ^c | |
|---------------------------------------|--------------------|---------|--|---------|---|---------|
| | corr | Pr > R | corr | Pr > R | corr | Pr > R |
| <i>Q. Jharkar-2</i> | | | | | | |
| Leaf N _{area} | -0.34 | 0.22 | 0.42 | 0.08 | — | — |
| Leaf N _{total} | -0.23 | 0.33 | -0.36 | 0.0001 | — | — |
| Neck blight area | 0.19 | 0.38 | — | — | -0.29 | 0.30 |
| Neck blight sev | -0.08 | 0.84 | — | — | -0.28 | 0.13 |
| <i>n=15</i> | | | | | | |
| <i>Khosa-2</i> | | | | | | |
| Leaf N _{area} | 0.32 | 0.05 | -0.60 | 0.01 | — | — |
| Leaf N _{total} | -0.58 | 0.008 | -0.34 | 0.001 | — | — |
| Neck blight area | -0.05 | 0.87 | — | — | 0.48 | 0.00 |
| Neck blight sev | -0.08 | 0.77 | — | — | -0.49 | 0.00 |
| <i>n=15</i> | | | | | | |
| <i>Shyela-1</i> | | | | | | |
| Leaf N _{area} | -0.34 | 0.28 | 0.59 | 0.00 | — | — |
| Leaf N _{total} | -0.43 | 0.10 | 0.43 | 0.01 | — | — |
| Neck blight area | -0.58 | 0.00 | — | — | -0.83 | 0.0001 |
| Neck blight sev | -0.58 | 0.00 | — | — | -0.81 | 0.0001 |
| <i>n=15</i> | | | | | | |

^aVariables correlated against yield of rough rice and N_{content} of grain. Leaf N_{area}—severity of leaf blight (% diseased leaf area), leaf N_{total}—severity of leaf N_{total} (% diseased leaf area), Neck blight area—percentage of neck blight. Neck blight sev—severity of neck blight.

^bYield/yield of rough rice (kg ha⁻¹) for each cultivar

^cChange of N in leaf/area and content of N in grain tissue. Pairwise comparison (one-tailed, leaf N_{total} was compared with content of N in leaf/area only. Neck blight incidence and severity was compared with rate of N in grain tissue only.

Table 4.18. Pearson correlation coefficients for leaf/blast, leaf/wound, seed/blast and severity of neck blast of rice vs. yield and range Σ content, by cultivar at La Libertad

| Cultivar and Variable ^a | Yield ^b | | Leaf Σ Content ^c | | Range Σ Content ^d | |
|---------------------------------------|--------------------|---------|------------------------------------|---------|-------------------------------------|---------|
| | corr | Pr > R | corr | Pr > R | corr | Pr > R |
| Q. Salinas 3P | | | | | | |
| Leaf/blast | -0.27 | 0.62 | -0.61 | 0.02 | — | — |
| Leaf/wound | -0.23 | 0.33 | 0.29 | 0.38 | — | — |
| Wound/blast ave | 0.21 | 0.44 | — | — | 0.30 | 0.43 |
| Wound/blast ave | 0.04 | 0.85 | — | — | 0.44 | 0.09 |
| n=13 | | | | | | |
| Eden 3 | | | | | | |
| Leaf/blast | -0.38 | 0.0003 | 0.66 | 0.006 | — | — |
| Leaf/wound | -0.57 | 0.00 | -0.66 | 0.007 | — | — |
| Wound/blast ave | -0.61 | 0.00 | — | — | -0.48 | 0.05 |
| Wound/blast ave | -0.17 | 0.007 | — | — | -0.48 | 0.005 |
| n=13 | | | | | | |
| Q647 3AP | | | | | | |
| Leaf/blast | 0.69 | 0.004 | 0.76 | 0.00 | — | — |
| Leaf/wound | -0.31 | 0.23 | -0.76 | 0.00 | — | — |
| Wound/blast ave | 0.33 | 0.05 | — | — | -0.49 | 0.06 |
| Wound/blast ave | -0.70 | 0.004 | — | — | 0.62 | 0.01 |
| n=13 | | | | | | |

^aVariables correlated against yield of rough rice and Σ content of straw. Leaf/blast=severity of leaf/blast (% diseased leaf area), leaf/wound=severity of leaf/wound (% diseased leaf area), Wound/blast ave=average of neck blast, Wound/blast ave=severity of neck blast

^bYield (g) of rough rice (g m⁻²) for each cultivar

^cContent of Σ in leaf tissue and content of Σ in root tissue. Foliar diseases (leaf/blast, leaf/wound) were compared with content of Σ in leaf tissue only. Wound/blast (average and severity) were compared with content of Σ in straw tissue only.

correlation was found between leaf blight and St content of leaf tissue ($P < 0.05$) (Table 3.9). No significant correlations were found between either incidence or severity of neck blight and either yield or St content of stem tissue (Table 3.9). Leaf wilt significantly reduced yield in Santa Rosa on Cyprus Lines 1, as determined by the negative correlation between yield and St content of leaf tissue ($P < 0.05$). Both leaf blight and wilt were negatively correlated with yield and St content of leaf tissue for the partially blight resistant Lines 2 ($P < 0.05$) (Table 3.9). Incidence and severity of neck blight was not a major factor in reducing yields of Lines 2, as the correlation between the incidence and severity of neck blight was not correlated with yield. Both incidence and severity of neck blight were negatively correlated with St content of stem tissue ($P < 0.05$) (Table 3.9). Significant correlations were found between leaf blight and leaf wilt and yield in Lines 2, as well as St content of leaf tissue. No correlations were found between leaf blight or leaf wilt and yield on the blight susceptible Cyprus 1, but both were negatively correlated with St content of leaf tissue. Neck blight was negatively correlated with yield of Cyprus 1, as was St content of stem tissue.

At La Taberna, yield of the blight-resistant cultivar Cyprus Sabana 18 was not significantly correlated with leaf wilt or neck blight ($P < 0.44$) (Table 3.10). Yield was negatively correlated with leaf blight on Cyprus Sabana 18, as well as with St content of leaf tissue (Table 3.10). Significant negative correlations were found between yield and leaf blight, leaf wilt and neck blight for Lines 2 (partially blight-resistant) ($P < 0.05$). Leaf blight, leaf wilt and neck blight were influenced by St content of leaf and neck tissue for Lines 2. Significant negative correlations were found between St content of plant tissue and incidence ($P < 0.05$). Only leaf and neck blight were significantly correlated with

yield and SI content in leaf and root tissue for BLAT 143 (which is susceptible), while leaf and root did not influence other parameters.

Discussion

Severity of leaf blight, severity of root rot, and both incidence and severity of root blight in this study were influenced by the type of resistance (qualitative, partial or complete susceptibility) expressed by each cultivar planted at Santa Rosa and La Laboral, as has been reported in the literature (24,17,113). Previous reports (40-46,170,120) regarding the ability of *Is* to reduce alternaria, such as leaf and root blight and leaf rot, were confirmed by experiments reported herein. Levels of leaf blight were considerably lower than for tests conducted previously at these two sites due in part to the later than normal planting dates. Because the tests were initiated later in the growing season, environmental conditions, especially rainfall, were not optimal for development of severe epidemics of leaf blight (Dr. Fernando Torres, personal communication).

The application of SI significantly reduced the severity of leaf blight on Lince 2 (partially blight resistant) and on Oryzon 1 (susceptible) at Santa Rosa. There was no significant reduction in the severity of leaf blight attributable to the rate of *Is* on the blight resistant cultivar Oryzon Lince 3, most likely due to the high level of resistance to leaf blight in the host. The severity of leaf blight on the cultivar never reached levels higher than 8.8%, making it extremely difficult, if not impossible, to detect any significant change in disease that could be linked to *Is*. A decrease of 7.3% in severity of leaf blight was noted for both Lince 2 and Oryzon 1 as the rate of SI increased from 0 to 1000 kg ha⁻¹, however, the rate of change in severity of leaf blight was greater for Oryzon 1 than for Lince 2. Severity of leaf blight decreased 3.84% on Oryzon 1 for each 1000 kg of SI

applied, while the rate of decrease on Lotus 2 was only 0.27%. The substantially higher level of leaf blight on *Oryzias* 1 versus that observed on Lotus 2 resulted in a larger magnitude response to *B* by *Oryzias* 1, and is a reflection of the type of resistance to *B* possessed by each cultivar.

Overall severity of leaf blight was less at La Libertad than at the Santa Rosa site. Although *B*-tolerant, *Oryzias* Sabana 10 was more susceptible to *B* grown than the *Oryzias* Lotus 3, which was planted at Santa Rosa. Increased rates of *B* provided significant reductions in the severity of leaf blight on all cultivars planted at La Libertad, although the greatest rate of decrease was observed for the partially resistant Lotus 2 and most-susceptible BLAT 140. The cultivar BLAT 140 had greater initial severity, at 8 kg of *B*/ha², of leaf blight than Lotus 3 but lower final severity values at the 3000 kg/ha² rate of *B*. Geographical differences between BLAT 140 and Lotus 3 could have resulted in different initial amounts of uptake and utilization of *B* in each cultivar (46,101,112).

Both incidence and severity of neck blight on *Oryzias* Lotus 3, Lotus 2 and *Oryzias* 1 at Santa Rosa reflected the response to leaf blight observed for these cultivars. The application of *B* was effective in reducing the incidence and severity of neck blight on the partially *B*-tolerant and most-susceptible cultivars at each rate tested, and there were only minor differences in the magnitude of reduction of disease observed between the two. At Santa Rosa, the severity of neck blight was lower than incidence of neck blight on Lotus 2 and *Oryzias* 1 at each rate of *B*, and cultivars with higher ratings of neck blight incidence had higher severity of neck blight. Because maintenance was restricted as recommended by the International Rice Research Institute (74) by using only short

patients with severe-type symptoms (rating 5-8), higher values of incidence translated into higher values of severity [74].

At La Libertad, the overall level of incidence and severity of neck blatt was higher than in Santa Rosa. Solera application on top residual soil affected the incidence or severity of neck blatt on the resistant Oryza Sativa 10, although this culture showed significantly higher levels of neck blatt than leaf blatt. Additionally, the partially blatt resistant Loma 2 had a lower severity of leaf blatt than Oryza Sativa 10. Several workers have noted that high levels of resistance to leaf blatt do not always correspond with high levels of resistance to neck blatt, and that these differences can be attributed to environmental conditions at flowering or possibly shifts in the root composition of the pathogen population between the vegetative and reproductive stages of growth [14, 110-114]. Solera applied at 800 and 1000 kg ha⁻¹ reduced the severity of neck blatt on Loma 2 and BAT 141 to levels below those of Oryza Sativa 10 (most resistant). This again could be indicative of differential genotypic responses to fertilization, with 5t 3t must be noted that the root structure of the population of *M. grisea* at La Libertad was not as well characterized as the population at Santa Rosa, and because of this, the adverse disease on the blatt resistant check might have encountered one or more susceptible races of the pathogen (P. Correa, personal communication).

Researchers have shown previously that the concentration of 3t is not least important in the rate of 3t as soil increases [41, 42, 46, 116, 133]. These results were confirmed by the results from this study. At both Santa Rosa and La Libertad, the concentration of 3t in both leaf and root tissue, for all cultivars, was strongly and positively correlated with the rate of 3t applied to soil. The least concentrations of 3t in

leaf and stem tissue, obtained from plants at each location grown in the absence of S_a , was higher for all cultivars at Santa Rosa as compared to those grown at La Libertad. The amount of S_a present in the soil at Santa Rosa was approximately 4 ppm, while at La Libertad the concentration of S_a was less than 1 ppm. This could account for the overall higher leaf concentrations of S_a in leaves collected at Santa Rosa, and could also explain the greater response (in terms of rate of increase of S_a in leaves) to foliar sprays with S_a observed for these cultivars grown at La Libertad.

Significant correlations between S_a content of leaf or stem tissue and disease were found in this study. Earlier reports have provided evidence that levels of blight, mild and brown spot are negatively correlated with the amount of S_a that has applied to the deficient soils; however only Volk et al. (195) correlated the concentrations of S_a in all grown collected leaf tissue and severity of disease (43,45,137,138,139,140). Washburn (195) compared the incidence of neck blight and severity of mild with S_a concentrations of flag leaves, but did not always find negative correlations with disease and S_a concentrations of flag leaf tissue. Because concentration of S_a varies by plant part (21), it is possible that S_a content of the flag leaf is not representative of the condition of other disease tissues. In the present study, for all cultivars at both locations, severity of leaf blight was negatively correlated with the concentrations of S_a in leaf tissue collected at the time of disease evaluation. The incidence and severity of neck blight were negatively correlated with the concentrations of S_a in stem tissue (collected shortly after evaluation of disease) for Lotus 2 and Gypsum 1 at Santa Rosa, and Lotus 2 and W.A.1 140 at La Libertad. Significant correlations between incidence of neck blight and S_a concentration of stem tissue were not found for the blight resistant cultivars planted at either location,

however, a negative correlation ($P=0.05$) between the severity of neck blight and the *S. cerevisiae* infection score was found for *Oryza sativa* L. in La Libertad.

According to Cohen-Victoria and Douglas (24,26), high levels of resistance to blast in cultivars such as *Oryza* Linn. 2 and *Oryza sativa* L. are due to the expression of major blast resistance genes, although cultivars with major genes for resistance to neck blast are known to possess genes for partial resistance. In the case of neck blast, in this study, *S. cerevisiae* appears to exert a strong effect on the expression of resistance by the two blast resistant cultivars. Based upon the large reduction of leaf and neck blast that can be directly linked to resistance with *St* in partially blast resistant and blast-susceptible cultivars, it is likely that *S. cerevisiae* is a major component of partial resistance as defined by Parker (31,32). Partial resistance, which corresponds to van der Plank's "horizontal" resistance (33), results in a reduced epidemic rate (4) and levels of disease that fall in between those for completely resistant and susceptible cultivars. The overall effect of this type of resistance is to reduce spore production of the pathogen, which in turn reduces r . The overall amount of spore production can be affected by such components as infection frequency, latent period, and sporulation per lesion (35,34,35). The partially blast resistant cultivars examined in this study showed levels of resistance to leaf and neck blast that were intermediate in comparison to blast resistant and blast-susceptible cultivars, and the levels of disease were greatly decreased as *S. cerevisiae* was introduced. It is plausible that *S. cerevisiae* acts on components of complete, or vertical, resistance, which is known to affect the onset of disease (36), as well as the epidemic rate (31,37). In the present study, however, disease onset was observed to occur at nearly the same time for all cultivars (data not shown). While effects on onset

infection frequency, which up to value β_1 will increase. In other words, it is unlikely that β_0 acts to delay onset of disease.

It is generally considered that partial resistance is not the most effective means of reducing or spreading disease severity (14,36). For this reason, breeding programmes aimed with heavy severity of resistance have focused upon the development of lines with complete or durable resistance at the expense of partial resistance (34). When partially resistant lines are grown where blast is severe, they typically require inputs of fungicide to provide an economic return (36). The most logical choice for growers in these regions is to plant resistant cultivars; however, it is not uncommon for blast-resistant cultivars to become susceptible within a few years following their release. Such farmers would then have to apply chemicals to control blast on their various losses (13,36).

One of the objectives of this study was to determine if applications of β_0 to rice in the partially blast-resistant and blast-susceptible cultivars could decrease total and peak blast to levels observed for resistant cultivars grown without β_0 . With regard to total blast, applications of β_0 at 300 or 1000 kg/ha² reduced severity of total blast in partially blast-resistant cultivars to levels equal to those seen in blast-resistant cultivars at both locations. At La Libertad, the severity of total blast on GRAT 143 that had received 300 or 1000 kg of β_0 ha⁻² was not significantly different than that for Dryden Toluca 10 (blast-resistant) without β_0 ; however, β_0 applications, regardless of rate, did not reduce the severity of total blast on Dryden 1 to the same level as Dryden Libertad 1 without β_0 . The overall effectiveness of β_0 in partially blast-resistant and blast-susceptible cultivars at La Libertad could have been greater due to the lower disease severity as compared to Santa

Rates, or genetic differences in the cultivars themselves. The application of Se at 1000 kg ha^{-1} reduced the incidence of neck blast on Lanes 2 (at Santa Rosa) as well as the resistant cultivar-wildcard Se . Similar responses were not observed on Deyllos 304 or Lanes 2 or 1000 kg ha^{-1} of Se at La Libertad, all sites of Se reduced incidence and severity of neck blast to levels lower than those observed on the blast-resistant cultivar. It is clear that the response of partially resistant and susceptible cultivars to inoculation with Se for the rice tested is dependent upon the overall severity of disease at a given location. Higher inherent severity of disease at specific sites may require larger amounts of Se inoculum to reduce head and neck blast as effectively as blast resistant cultivars.

Leaf-blast was more severe than head blast on all cultivars at Santa Rosa and La Libertad. No differences in susceptibility to scald were detected among cultivars at Santa Rosa, while ELAT 143 was more resistant than Deyllos 304 and Lanes 2 at La Libertad. Regardless of the cultivar, severity of leaf scald was reduced by inoculation with Se . Severe concentrations of leaf scald was negatively correlated with severity of scald on all cultivars at Santa Rosa and on Lanes 2 at La Libertad. Leaf-blast is considered to be a disease of minor importance at rice when early photographs made, but can occasionally cause yield reductions with later photos (H. J. C). Leaf-blast is typically a late season disease (30) and appeared in other tests at that location prior to appearing in this study. Leaf-blast was more severe at Santa Rosa than at La Libertad. The rice at Santa Rosa was planted a month later than normal and could have been subjected to higher risk of infection than neighboring tests. While the mechanism by which Se reduces scald is unknown, it is important to note that infection by the causal

agent of mold, *Micrographella salweeni*, is through stomata. A physical barrier of SiO_2 in the cuticle layer of the rice leaf's HZ would likely not affect the presence of infection by *M. salweeni*. Perhaps increased SiO_2 in the epidermis of the rice leaf acts to reduce fungal exposure. In any period, or when other factors involved in grain production.

Yields of rough rice were increased on all cultivars at both locations by the applications of Si at rates of 800 and 1 600 kg/ha², confirming previous reports of the yield-enhancing potential of the HZ (21–26, 37, 134–135). The cultivars planted at Santa Rosa, as a group, yielded higher than those planted at La Libertad. Genotype differences between the two groups of rice cultivars and differences in soil fertility between the two sites could be responsible for higher yields at the Santa Rosa site. Increases in yield due to the application of Si have been attributed to control of diseases such as blast and brown spot, and to improved plant nutrition (47, 56, 177, 180). In this study, the colored leaf and neck blast is the reduction of yield caused by *Pyricularia*. There was no significant correlation between incidence or severity of neck blast and yield of rough rice from blast-resistant cultivars or other factors, or of the partially blast-tolerant cultivar at Santa Rosa. A highly significant negative correlation was found between the incidence and severity of neck blast and yield for *Oryza 1* and *IR62-140* (both blast susceptible) and for *Unas 7* at La Libertad. Leaf blast was negatively correlated with yield of rough rice for *Unas 7* (Santa Rosa) and all cultivars planted at La Libertad. Yield was negatively correlated with leaf mold on all cultivars at Santa Rosa, and was of greater importance in the reduction of yield than leaf blast. At La Libertad, only plots of *Unas 7* were negatively impacted by leaf mold. Clearly, increased yield cannot be explained entirely

by the reduction of harvest by Se_0 and most also by a function of improved Se nutrition in the new plant.

Of the components of yield measured, grain fill and the weight of filled grains for all cultivars was most strongly affected by fertilization with Se . The number of panicles/pl² and thousand grain weight were increased on all cultivars at La Libertad. Both Doran et al. (94) and Hla et al. (94) have reported that grain fill is the component of yield most significantly impacted by fertilization with Se . Fertility of spindles within a panicle is enhanced by fertilization with Se (95), and as reflected in the increase in the number of filled grains when Se is applied. Improved control of leaf and neck blight by Se contributes responsible for improved grain fill in this study. Fungal diseases such as leaf blight and leaf scald are known to reduce photosynthesis, thereby reducing total available nutrients for the production of grain. Neck and/or spike sheath and panicle blight, resulting in partial or complete blockage of the flow of nutrients to developing grain. There is less robust spikelet density and grain fill (95,110).

In addition to improving quantity of yield, fertilization with Se improved the quality of yield, regardless of the cultivars, at both locations. The percentage of whole grains harvested increased linearly as the rate of Se applied to soil increased. The percentage of grains broken during the milling process is directly related to grain maturity and moisture level (43,48). Overripe or under ripe grains tend to be more fragile, as do heavily-damaged grains or grains damaged by insect feeding. In addition to reducing diseases, Se is known to promote earlier panicle maturity and uniform ripening of grains (48). The improvement in milling quality for Se treated cultivars at Santa Rosa was significantly correlated with the rate of Se applied, however, no significant correlations

were found for milling quality at La Libertad. Grain deterioration was also significantly reduced in all cultivars at both locations by the application of *Is*. These data are in agreement with Windsor (1972), who reported that the application of azoxystrobin at 0.05 g/a did not affect yield or grain deterioration in African rice grown on single rice genotypes. Reduction in grain deterioration improves the milling quality of rough rice and also the overall grade, thereby increasing the value of a given crop of rice.

Selenicene can be used successfully with blast-resistant and partially blast-resistant cultivars to manage leaf and neck blast, and also leaf smut. Depending upon the rate of *Is* fungicide applied to *Is*-tolerant rice, the severity of these diseases on susceptible and partially resistant cultivars can, in some cases, be reduced to the same levels as those observed for blast-resistant cultivars. This could make *Is* a useful tool for managing rice diseases, possibly in conjunction with cultural practices of fungicide or specific rates of application, and may provide alternatives to rice growers in areas where blast-resistant cultivars have become susceptible due to shifts in populations of *M. grisea*. Disease-tolerant breeding for resistance to multiple diseases can be difficult, the ability of *Is* to reduce disease such as leaf smut provides an alternative for control of these diseases. The improvements in yield and quality of yield-diminished milling quality and reduction of grain deterioration as alternatives obtained through fertilization with *Is* could provide a means for rice growers in upland ecosystems and in other temperate environments, to realize significant economic gains with only a minor increase in input costs. Once where blast-resistant cultivars are deployed, improvements in yield and yield quality alone would justify the application of *Is* fungicides. According to McCluskey (1977) demand for rice will increase by more than 60% in the next 30 years as the world's population increases.

In areas where plant-available Si sources are deficient, supplying an adequate level of Si to growers in that study, could raise yields by up to 40% and help our growers meet the demand for greater production of rice in the coming years.

CHAPTER VII EFFECT OF SILICON ON COMPONENTS OF RESISTANCE TO BLAST IN SUSCEPTIBLE, PARTIALLY RESISTANT, AND RESISTANT CULTIVARS OF RICE

Introduction

Blast blight, caused by *Magnaporthe oryzae* (Hikari) Barr., is the most destructive fungal disease of rice, particularly in temperate, irrigated rice and tropical upland rice (1,5,10). The pathogen can infect all above-ground parts of the rice plant, but is most common on leaves or leaf blades during the vegetative stage of growth or on neck blast on neck or the unfurling branches during the reproductive stage (16,18,19). Although not as damaging as neck blast, leaf blast can be severe in tropical upland rice and can significantly reduce leaf area and yield in some cases (10,19).

Cultivars of rice with either complete or partial resistance to blast are widely utilized to control the disease (15,18,20,21,22). Complete resistance, which corresponds to rice *durabilis* (14) natural resistance, is characterized by a hypersensitive-type response to infection and tends to be short-lived in nature due to the appearance of pathogenic races of *M. oryzae* not affected by specific major genes for resistance (15,24). This is a result of natural variability in populations of *M. oryzae*, or of a failure to select and advance breeding materials in the presence of pathogen populations that represent those encountered in commercial fields (24,26,28). Cultivars of rice with partial resistance to blast are highly effective in controlling the disease, especially in tropical lowland environments (17). Partial resistance, also referred to as locational or race

reducing resistance, is controlled in plants by multiple genes that have qualitative effects against the pathogen, and is thus more durable in nature (94,114,147). Partial resistance, as defined by Parker *et al.* (114), is a type of incomplete resistance characterized by reduced production of spores despite a susceptible-symptomatology by the host to the pathogen. The overall effect of fewer spores is a reduction in the rate of epidemic progress. Cultivars of rice with complete resistance to blast may also possess some degree of partial resistance (113,142).

Like reducing resistance to plant diseases has been shown to be affected by various components that act to limit the production of spores as secondary inoculum by a given pathogen (114). Reductions in the rate of progress of an epidemic in plants with partial resistance to various pathogens have been associated with a lengthened latent period (period between inoculation and appearance), reduced infection efficiency (the number of sporulating lesions per unit of inoculum), reduced lesion size (length or diameter), reduced rate of lesion expansion, shortened period of sporulation, and reduced number of spores per lesion (11,21,71,108,109,114,116,117,123,138). Rowson (123) found no difference in latent period or incubation period, which is the period between inoculation and appearance of symptoms of a disease among three cultivars of rice with varying degrees of partial resistance to rice blast; however, cultivars expressing high levels of partial resistance had fewer sporulating lesions per leaf and smaller sporulating area per lesion than cultivars with lower or no resistance to blast. Other researchers indicate that some variability in latent period of rice blast exists between cultivars of rice with partial resistance to rice blast (21,119). Yeh and Rowson (119) reported that sporulation from individual lesions, as determined by washing lesions from leaves,

leaves of black, was significantly greater for black susceptible cultivars than for partially resistant and resistant cultivars.

The application of silver (Ag) or zinc sulfide (Zn) has been shown to reduce the severity of rice blast in both irrigated and upland rice (43,42,47,48,49,50,51). Work presented in chapters 2 and 3 of this dissertation suggests that Ag reduces the rate of progress of blast epidemics, and that Zn influences the expression of partial resistance to blast. However, little is known about the effects of interactions with Zn on components of resistance to rice blast. Yellin et al. (148) demonstrated that increased levels of Zn in rice leaves of rice decreased the number of sporulating lesions per leaf when associated with a lower concentration of incidence of *M. grisea*, indicating an effect of Zn on the infection efficiency of the blast pathogen. Silver has been shown to affect several components of resistance to powdery mildew of cucumber (383). They found that resistance efficiency of *Sphaerotheca fuliginea* colony size and germination of ascus were reduced when cucumbers were grown on nutrient solutions with high concentrations of Zn.

The purpose of this study was to evaluate the effects of rates of Zn on several components of resistance to rice blast for cultivars with no resistance, partial resistance or complete resistance to rice blast. Components of resistance evaluated were incubation period, latent period, infection efficiency, lesion size, proportion of leaf area with lesions, rate of lesion expansion, and levels of sporulation per lesion.

Materials and Methods

Experiments on components of resistance to rice blast were conducted at professors at the University of Florida at Gainesville. Rice cultivars 'M201', 'Lousiana', 'Lemont', and 'Katy' were chosen to represent a range of resistance types to

rate B-49 of *M. grisea*. Cultivar 'M201' has no major genes for resistance to race (B-49) and is completely susceptible. 'Bastogne' and 'Lamont' are partially resistant to race (B-49, and 'Key' is completely resistant (M.A. Munkittrick, personal communication).

The following components of resistance were evaluated as each cultivar: incubation period, latent period, infection efficiency (lesions/cm²), total area of lesions per leaf, spore number per lesion, and daily rate of lesion expansion.

The seed type used was a 3x defoliated Hybrid (Tern Cross stock), obtained from the New Hope Sugar Corp. near Belle Glade FL, with a B content of approximately 3.0 mg L⁻¹. Topolium cups measuring 10.5 × 17 cm were filled with sand and saturated with calcium chloride (Vasol W 20 R T, Vardahol, Norwalk CT) at rates equivalent to 0, 2, 4, and 10 meq/L base (T) ha⁻¹. Available calcium (S from Vasol W 20) was approximately 20%. Calcium carbonate was added to cups treated with 2, 4, and 8 T ha⁻¹ calcium chloride to equalize the amount of calcium on each treatment with the amount present in the 10 T ha⁻¹ treatment (3.3 g per cup). Seeds of each cultivar were preselected on petal plates and sorted at a rate of five seedlings per cup. At approximately 10 days after planting, each cup was divided in two plates. No such division was made in the cups to allow for drainage, and plates were kept under flooded conditions until time of inoculation. The experiment was conducted in completely randomized design with 16 treatments and three replications. All experiments were repeated three times, with the exception of the lesion size and sporulation studies (repeated once only).

Inoculations were made at dusk or at about the time of emergence of the sixth or seventh leaf from the bottom of the main stem, which was approximately 25 days after planting, using an aerosol sprayer (Crown Signi-Treat, Fisher Scientific, Pittsburgh, PA).

Twenty milliliters of a conical suspension was applied as a fine mist to the two plants per rep. Inoculum was obtained as follows: isolate 793-21411 of *M. grisea* was grown on 20% V8-agar to produce sporulation. On the day of inoculation, a petri plate containing a sporulating culture of isolate 793 was flooded with 1 ml of distilled water and scraped with a rubber policeman. The resulting suspension was then homogenized and adjusted to a concentration of 1.2×10^7 conidia ml^{-1} . Distain was added at 1% v/v to the conoidal preparation to act as a stain on leaf surfaces. Inoculated plants were transferred to a mist chamber and maintained at 100% R.H. for 12 hours. Plants were then removed and kept dry until the appearance of symptoms of blight. When symptoms appeared, each plant was placed in a polyethylene bag and leaves were washed with a hand sprayer to reduce sporulation. Bagged plants were maintained in an incubation chamber at 22 °C for the duration of the experiment.

Resistance to *M. grisea* is known to increase at leaf tips of the rice plant over time; therefore, leaves 2 and 3 on the main tiller of each plant were used to assess that leaves used to evaluate components of resistance to blight were of the same age class. Incubation period, latent period, and lesion expansion were determined on detached leaves. Incubation period was scored as the date of appearance of necrotic flecks (necrotic lesions) on marked leaves. Five randomly-chosen leaves per rep were examined for the presence of conoidal water-based leaf suspensions (10^7) every 24 hours to determine the beginning of sporulation. Latent period for each treatment was used as the time at which 50% of the leaves, or three of the five tested, began to sporulate (LP_{50}). The daily rate of lesion expansion was calculated by employing a digital caliper to measure the length (mm) of the emerging lesions on marked leaves on the last day of emergence, followed by daily

measurements that ended when responses ceased. Depending upon the treatment, fewer than five lesions were evaluated on the treatment 'Katy' due to a lack of lesions.

Sporelation per lesion was determined on the following manner. Five sporeulating lesions per petri were assessed and each placed in a Petri dish containing 1 ml of a 15% v/v solution of copper sulfate plus a small drop of a 1% v/v solution of Tween X-100 (Rohm and Haas, Philadelphia PA). Copper sulfate was added to the suspension to prevent germination of the oocysts. These were then stored at 2°C until evaluation. Vials were agitated vigorously using a Vortex Genie 2 (Scientific Industries, Bohannon NY) for two minutes. Following agitation, 10 samples were drawn from each vial and the number of oocysts were counted with a hemacytometer and mathematically related to the number of oocysts and ³ because lesions were varied using lesions for a given treatment and between lesions from different treatments, the number of oocysts ml⁻¹ was adjusted to reflect size of lesions as follows. After counting oocysts, removed lesions were removed from Petri dishes and fixed to a sheet of paper. Each group of five lesions (from each treatment) was then digitally photographed with a Canon RE-450-Mk II Video Videocam (Canon USA, Lake Success NY) and captured on a personal computer with a TRIGA+ frame grabber (Stratavision, Inc., Indianapolis IN). Area of lesions (mm²) was determined by analyzing stored images with Sigma Scan Pro version 3.0 (Jandel Scientific, San Rafael CA). The number of oocysts from a given lesion was then divided by the corresponding lesion size to obtain the number of oocysts per mm² of lesion. Due to a lack of lesions, between size and dose were evaluated for 'Katy', depending upon the rate of oocyst release.

When all lesions had emerged on detached leaves a leaf reached maximum size, two leaves from each cup were removed and fixed, using double-sided tape to 21.8 × 28 cm sheets of paper. Leaves from each treatment were photographed as described previously. Leaf area, number of sporulating lesions, size of sporulating lesions (measured as length of the longest axis of each lesion), total leaf area with lesions was estimated from scanned digital images using Figure from Pro v. 2.0. Sporulation of fully expanded lesions was visualized prior to photography of each leaf with a hand-held microscope (100×). The number of sporulating lesions was divided by total leaf area to obtain a relative number of lesions per cm² of leaf. A visual estimation of total area with lesions must be made for comparison with computer-generated values.

Approximately 10 g of leaf tissue were harvested from each treatment and dried for analysis of Si residues. Dried leaves were ground in a Wiley-mill (Thomas Scientific, Swedesboro, NJ) to pass through a 40-mesh screen. Ground tissue was assayed using the molybdenum reduction procedure of Tillen and Snyder (48). Percent Si of tissue was determined from the digitized using molybdenum calibration analysis.

Data were analyzed by analysis of variance (ANOVA) and linear regression where appropriate using SAS for Windows version 6.12 (SAS, Cary NC). Log transformation was employed wherever data were not normally distributed. Comparisons of visual estimates of disease with those obtained by using Figure from Pro were made by analyzing differences in areas with the survival procedure (SAS, Cary NC).

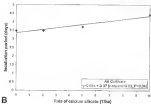
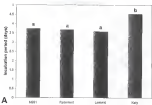
Results

The interaction between male effects was not significant for each of the components tested ($P > 0.05$) (Table 5.1); therefore, means are presented by cultivar, averaged across rate of colonisation (and by rate of colonisation, averaged across cultivar).

Incubation and latent periods. Incubation period ranged from 5.5 to 4.5 days, depending upon the cultivar (Fig. 4.1a). No significant differences in incubation were found among 'McMur', 'Kesteven', and 'Lancet' ($P > 0.05$), however, the incubation period of the resistant cultivar 'Kest' was significantly longer than for the remaining cultivars ($P < 0.001$) (Fig. 4.1a). Regardless of cultivar, incubation period increased in a significant, linear manner as the rate of colonisation increased ($P < 0.001$) (Fig. 4.1b-c). The increase in incubation period associated with higher rates of B was more pronounced for 'Kest' than for the remaining cultivars (Fig. 4.1a). Latent period ranged from 5.47 to 4.77 days and did not differ significantly between cultivars ($P > 0.10$) (Fig. 4.2a). No significant linear relationship was found between latent period and rate of colonisation for any of the cultivars tested ($P > 0.05$) (Fig. 4.2b-c). Latent period was significantly longer on 'Lancet' and 'Kest' than on the remaining cultivars at 2 and 3 T of B ha^{-1} , but was significantly lower at 10 T of B ha^{-1} (Fig. 4.2a).

Relative infection efficiency. Relative infection efficiency of B grown, determined as the number of sporulating lesions per mm^2 of leaf area, was highest on 'McMur' and 'Kesteven' and lowest on 'Kest' (Fig. 4.3a). The cultivar 'Lancet' had 50 and 75% fewer sporulating lesions per leaf area than 'McMur'. Relative infection efficiency was 87% lower on 'Kest' as compared to 'McMur', and was significantly lower

Fig. 4.1 Effects of calcium silicate, applied at 0, 1, 5, and 10 t ha⁻¹, on incubation period of *M. grisea* for the cultivars 'MORR', 'Maurmont', 'Lancost', and 'Katy' of rice. Part (A) represents mean incubation period of *M. grisea* for each cultivar, averaged across rates of calcium silicate. Part (B) illustrates the relationship between incubation period and rate of calcium silicate; averaged across means for all cultivars. and (C) shows effects on incubation period for each cultivar and rate of calcium silicate. Bars with the same letter in (A) do not differ significantly at $P=0.05$ as determined by Fisher's protected LSD test. Bars in (C) represent standard errors of means. All data are the mean of up to 3 means per treatment, three replicates, and three experiments of the experiment.



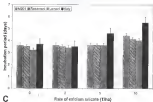
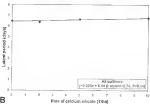
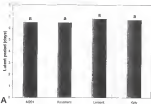


Figure 1 — Continued

Fig. 6.2 Effects of sodium nitrate applied at 0, 2, 5, and 10 T ha⁻¹ on latent period of *M. grisea* for the cultivars ‘Millo’, ‘Korona’, ‘Luzern’, and ‘Katy’ of rye. Part (A) represents mean latent period of *M. grisea* for each cultivar, averaged across rate of sodium nitrate. Part (B) illustrates the relationship between latent period and rate of sodium nitrate, averaged across means for all cultivars, and (C) shows effects on latent period for each cultivar and rate of sodium nitrate. Bars with the same letter in (A) do not differ significantly at $P=0.05$ as determined by Fisher’s protected LSD test. Bars in (C) represent standard errors of means. All data are the means of up to 3 isolates per treatment, three replications, and three repetitions of the experiment.



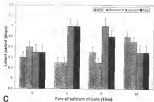
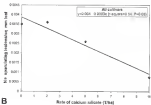
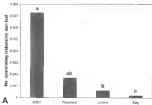


Figure 3 — (Continued)

Fig. 4.3 Effects of calceare nitrate applied at 0, 2, 5, and 18 T ha⁻¹ on the number of sporulating lesions of wheat (relative reduction of biomass) the cultivars 'M200', 'Fusarium', 'Lancaster', and 'Katy' of rice. Part (A) represents the mean number of sporulating lesions mm⁻² of leaf for each cultivar, averaged across rate of calceare nitrate. Part (B) displays the relationship between the number of sporulating lesions mm⁻² of leaf and rate of calceare nitrate, averaged across means for all cultivars, and (C) shows effects on the number of sporulating lesions mm⁻² of leaf for each cultivar and rate of calceare nitrate. Bars with the same letter in (A) do not differ significantly at P=0.05 as determined by Fisher's protected LSD test performed on log-transformed values. Bars in (C) represent standard errors of means. All data are the means of two harvests per treatment, three replicates, and three repetitions of the experiment.



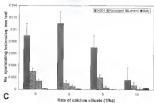


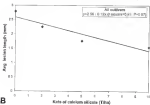
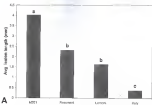
Figure 6.3 — Continued

when compared to 'Ransom' or 'Lemon'. The relationship between number of sporulating lesions per leaf area and rate of colonisation always was linear and significant for all isolates ($P < 0.05$) (Fig. 6.3b). There was no significant change in the number of sporulating lesions on 'Katy' at any rate of colonisation (Fig. 6.3c), however, the means for 'Katy' are included in the analysis of main effect, for rate of colonisation, due to a lack of interaction between main effects. When the rate of colonisation was increased from 8 T ha^{-1} to 16 T ha^{-1} , the number of sporulating lesions per leaf area decreased by more than three 90% on 'M201', 'Ransom', and 'Lemon' (Fig. 6.3b-c).

Lesion length. Lesion length was longer for 'M201' than for 'Ransom', 'Lemon', and 'Katy' ($P < 0.05$) (Fig. 6.4a). Lesion length did not differ significantly between 'Ransom' or 'Lemon', and lesion length was lowest for 'Katy' ($P < 0.05$) (Fig. 6.4a). Considering all cultivars, lesion length was significantly reduced by 76–88% when the rate of Σ increased from 8 T ha^{-1} to 16 T ha^{-1} ($P < 0.05$) (Fig. 6.4b-c). At OT of Σ ha^{-1} , lesions on 'M201' and 'Ransom' did not differ in length (Fig. 6.4a).

Lesion expansion. Regardless of the rate of Σ , the daily rate of lesion expansion was significantly higher on 'M201' than on 'Ransom', 'Lemon', or 'Katy' (Fig. 6.5a). Rate of lesion expansion was 62 and 97% slower on 'Ransom' and 'Lemon', respectively, as compared to 'M201' and did not differ significantly between these two cultivars. Rate of lesion expansion was significantly slower ($P < 0.05$) by 100% 'Katy' than on 'Ransom', 'Lemon', or 'M201' ($P < 0.05$) (Fig. 6.5a). For all cultivars, rate of lesion expansion significantly decreased from 0.8 to 0.4 mm/day (45%) as the rate of colonisation increased from 8 T ha^{-1} to 16 T ha^{-1} ($P < 0.05$) (Fig. 6.5b-c). The daily rates of lesion

Fig. 4.4 Effects of calcium silicate applied at 0, 1, 2, and 30 T ha⁻¹ on length of root lesions for the cultivars 'MK4', 'Sonoma', 'Lemna', and 'Waty' of soy. Part (A) represents average lesion size for each cultivar, averaged across rates of calcium silicate. Part (B) illustrates the relationship between lesion size and rate of calcium silicate, averaged across means for all cultivars, and (C) shows effects on lesion size for each cultivar and rate of calcium silicate. Bars with the same letter in (A) do not differ significantly at $P=0.05$ as determined by Fisher's protected LSD test. Bars in (C) represent standard errors of means. All data are the means of up to four lesions per treatment, three replicates, and three repetitions of the experiment.



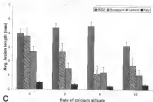
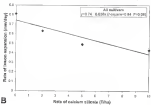
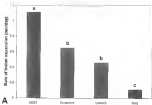


Figure 6.4 — Continued

Fig. 4-5 Effects of calcium silicate applied at 0, 5, 15 and 30 T ha⁻¹ on the daily rate of expansion of blast lesions for the cultivars 'M204', 'Rosenstein', 'Lancost' and 'Rory' of rice. Part (A) represents the rate of expansion of blast lesions for each cultivar, averaged across rates of calcium silicate. Part (B) illustrates the relationship between rate of lesion expansion and rate of calcium silicate, averaged across cultivars for all cultivars, and (C) shows effective rate of expansion for each cultivar and rate of calcium silicate. Bars with the same letter as (A) do not differ significantly at P=0.05 as determined by Fisher's protected LSD test. Data in (C) represent standard errors of means. All data are the mean of up to five biological replicates. Three replications, and three replications of the experiment.



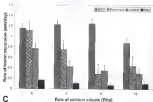


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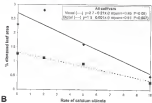
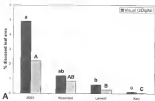
responses for 'MGR' and 'Ransom' did not differ significantly at 0.1 of 1% ($P_{0.1}$, 0.1%)

Lesion area per leaf Lesion area per leaf, as percent diseased leaf area, was significantly higher on 'MGR' and 'Ransom' than on 'Lemon' or 'Katy' ($P \leq 0.01$) (Fig. 4.4a). No significant difference in lesion area was found between 'Ransom' or 'Lemon' ($P \geq 0.05$). The cultivar 'Lemon' had 50% less diseased leaf area than 'MGR' (Fig. 4.4a). Lesion area was reduced by 14% on 'Katy' when compared to 'MGR'. For all cultivars except 'Katy', lesion area was significantly reduced by greater than 50% as the rate of addition of lesions increased from 0 to 12 T ha⁻¹ ($P \leq 0.01$) (Fig. 4.4b-c). There was no change in % DLA for 'Katy' at any rate of addition of lesions (Fig. 4.4c). Because the interaction between cultivars and rate of addition of lesions was not significant ($P \geq 0.05$), the means for 'Katy' are included in the analysis of the main effect for rate of addition of lesions.

Visual estimates of lesion area per leaf were strongly correlated ($r = 0.94$, $P < 0.001$) with those obtained by computerized analysis of digitized images of diseased leaves (Fig. 4.4d-f, Table 4.2). Visual estimates were significantly larger than computer-generated estimates of lesion area per leaf ($P \leq 0.05$) as determined by comparisons of mean differences with the *t*-test procedure (Table 4.2, Gray MC) (Fig. 4.4d-f, Table 4.2).

Number of spores per cm² of lesion The number of spores per cm² of lesion was different among 'MGR', 'Ransom', 'Lemon', and 'Katy' ($P \leq 0.01$) (Fig. 4.5a). Sporulation per cm² of lesions for 'MGR' was over three times higher than for 'Ransom', not two times higher than for 'Lemon'. Only 7 spores cm⁻² were measured from lesions on 'Katy' (Fig. 4.5a). For all cultivars, the relationship between rate of

Fig. 4.4 Effects of colostrum volume applied at 0, 2, 5, and 10 T/ha² on the percentage of leaf area with blight symptoms (%DLA) for the cultivars 'MIM1', 'Bismarck', 'Lorax', and 'Kay' as assessed visually or by digital image analysis. Part (A) represents the %DLA for each cultivar, averaged across rates of colostrum volume. Part (B) illustrates the relationship between %DLA and rate of colostrum volume, averaged across regions for all cultivars, and (C) the main effects on %DLA for each cultivar and rate of colostrum volume. Bars with the same letter and rate as (A) do not differ significantly at $P=0.05$ as determined by Fisher's protected LSD test performed on log transformed values. Bars in (C) represent standard errors of means. All data are the means of two leaves per treatment, three replicates, and three repetitions of the experiment.



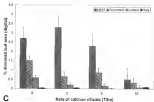


Figure 8.4 — Continued

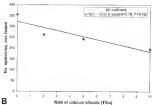
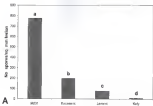
Table 4.2 Comparison of visual and computer-aided evaluations of severity of leaf blight on the cultivars 'M204', 'Kasamand', 'Lemond', and 'Katy' of rice. Each cultivar was treated with fungicide at 0, 2, 5, or 10 T ha⁻¹

| Visual vs. digital image analysis | | | | |
|-----------------------------------|----------------------|---------------------|----------------------------|---------|
| Avg. difference | | Pearson correlation | | |
| between means ^a | T-value ^b | P<(T) | visual/visual ^c | digital |
| 1.33 | 2.42 | 0.02 | 0.94 | 0.9991 |

^aCalculated as the difference between visual and computer-generated estimates of blight severity for 18 treatments

^bTest for linear correlation between visual estimates of blight severity and estimates obtained through digital image analysis for 18 treatments. Data represent the comparison of differences between means of evaluations made visually or with digital image analysis and were taken across 144 pairs of leaves representing 18 treatments, three replications, and three repetitions of the experiment

Fig. 4.9 Effects of sodium nitrate applied at 0, 2, 4 and 10 T ha⁻¹ on the sprouting of three cultivars of blueberries: 'Honey', 'Berkley', 'Lemont', and 'Raj'. Part (A) represents the number of sprouts m⁻² of leaves for each cultivar, averaged across rates of sodium nitrate. Part (B) illustrates the relationship between the number of sprouts m⁻² of leaves and rate of sodium nitrate, averaged across cultivars, and (C) shows effects on the number of sprouts m⁻² of leaves for each cultivar and rate of sodium nitrate. Bars with the same letter in (A) do not differ significantly at P=0.05 as determined by Fisher's protected LSD test performed on log transformed values. Bars in (C) represent standard errors of means. All data are the means of up to five leaves per treatment, three replicates, and three replications of the experiment.



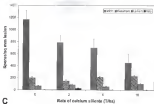


Figure 8.7 — Continued

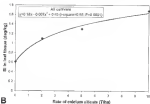
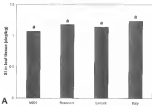
coloured tubules and the number of spores per mm² of leaves was lower, but significant only at $P=0.05$ (Fig. 4.3b-c). Sporulation on all cultivars per mm² of leaves was reduced by 45% as the rate of calcium tubulate increased from 0 to 10 T ha⁻¹. The lack of association between cultivar and rate of calcium tubulate for the number of spores mm² of leaves permitted the analysis of main effects only. However, a closer examination of the number of spores mm² of leaves by cultivar, for each rate of Ca, indicated that only M204 showed a decrease as the rate of Ca increased (Fig. 4.3c).

Percentage of Si in leaf tissue. The concentration of Si in leaf tissue, as determined (Fig. 4.4) did not differ significantly between 'M204', 'Rousselot', 'Lamont', or 'Katy' regardless of the rate of Si ($P=0.05$) (Fig. 4.4a, Fig. 4.4b). For all cultivars, the percentage of Si in leaf tissue was increased by more than 50% as the rate of calcium tubulate increased from 0 to 10 T ha⁻¹ ($P<0.001$) (Fig. 4.4b-c).

Discussion

The application of calcium tubulate at rates of 0, 2, 5, and 10 T ha⁻¹ to Si deficient H. erecta significantly affected more than one component of resistance to rice blast for the cultivars 'M204', 'Rousselot', 'Lamont', and, in some cases, 'Katy'. The amount of Si present in leaf tissue was found to increase for all cultivars when the rate of calcium tubulate was increased, indicating that effects on components of resistance were associated with Si content. However, the content of Si did not differ among cultivars when all rates of calcium tubulate were considered. Relative infection efficiency of *ir* genes was greatly affected by cultivar and rate of calcium tubulate in this study. As reported by Otero-Camacho *et al.* (1984) and Bourcier (1985), the relative infection efficiency of *ir* genes was lower on cultivars of rice with greater resistance to blast and

Fig. 4.18 Effects of calcium silicate applied at 0, 1, 3, 6, and 10 T ha⁻¹ on the concentration of silicon (Si) in leaf tissue for the cultivars ‘M309’, ‘Rosamund’, ‘Lancot’, and ‘Rory’ of oat. Part (A) represents the concentration, in dryweight (mg/kg of Si in leaf tissue) for each cultivar, averaged across rates of calcium silicate. Part (B) illustrates the relationship between Si content and rate of calcium silicate, averaged across means for all cultivars, and (C) shows effects on the content of leaf tissue for each cultivar and rate of calcium silicate. Bars with the same letters (A) do not differ significantly at $P=0.05$ as determined by Fisher’s protected LSD test. Bars in (C) represent standard errors of means. All data are the mean of three harvest per treatment, three replicates, and three replications of the experiment.



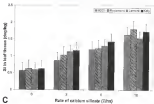


Figure 8.4—Continued

legumes more susceptible cultivars. As in the present study, both Otero-Castelán et al. (102) and Ramírez (115) defined relative collection efficiency as the number of sporulating lesions per unit of leaf area following inoculations with a known concentration of spores of *M. phaseae*. Based upon the magnitude of responses and statistical significance, relative collection efficiency was affected more by rate of till than the other components tested in this study. For all cultivars but 'Katy', the number of sporulating lesions was significantly reduced by nearly 50% when the rate of cultivar tillage was increased from 0 T to 2, 5, and 10 T ha⁻¹. These findings confirm previous reports that increased levels of till is the source of till susceptible cultivars of rice are associated with reductions in the number of lesions of till (101, 106). The effect of till on relative collection efficiency as determined by the number of sporulating lesions as reported on partially resistant or susceptible cultivars and in rice responses. In the case of 'Katy', the number of sporulating lesions found on plants that did not receive cultivar tillage was near zero. Therefore differences in relative collection efficiency at different rates of cultivar tillage was impossible to detect for 'Katy'. A similar response was reported by Otero-Castelán et al. (102), who found no differences in the number of sporulating lesions among resistant cultivars that had been grown in a volunteer containing till and those that had not received till.

It is important to note that the concentration of spores of *M. phaseae* used as inoculants in the present study was 10% lower than those used in previous studies (102, 113–140). Further testing at higher concentrations of inoculum should be conducted to determine if the effects of till on susceptible and partially resistant cultivars are altered by higher severity of leaf blight.

Severity of disease was measured in this experiment as the proportion of leaf area occupied by lesions (, and this reflected the number of sporulating lesions for each culture and rate of SI. Estimates of severity of disease made visually and with digital image analysis software were strongly correlated, however, visual estimates were consistently and significantly higher than those computed digitally ($P < 0.01$). Estimates of precision, visual estimates were similar to those obtained with digital analysis and were for repeated estimates. Computer-generated estimates were more accurate than visual estimates, but took considerably longer to calculate. It appears that digital image analysis is better suited to obtain measurements of numerous small objects such as lesions rather than for gross estimates of disease severity on small samples of leaves.

The size of lesions of *M. griseoviridula* on the level of resistance to that reported by each cultivar. Lesion size, measured as length, was greater for 'MOR', equal between 'Reinforced' and 'Lemon', and smaller on 'Key'. This pattern has been observed by Kautsky (1993) and Webb and Jensen (1995). The effect of rate of SI on lesion length was smaller in magnitude and statistically less significant than for relative infection efficiency (number of sporulating lesions). Unlike relative infection efficiency, lesion length was reduced on all cultivars by an average of 58% with increasing rates of SI. Therefore, the mechanism by which Si acts to reduce lesion size appears to complement mechanism(s) of resistance to that possessed by the cultivars tested in this study. Rate of lesion expansion was directly associated with the length of lesions. Lesions caused by *M. griseoviridula* are determined in size and, in this experiment, reached maximum size at roughly the same time for all cultivars and rates of SI (data not shown), resulting in measurements similar to those for length of lesion. Of these two components,

lesser length is most likely more important as a component of resistance to leaf-miner than rate of expansion. During the period of lesion expansion, sporulation was not observed on lesions from any level(s), but instead began at the point when symptoms had been reached. The rate of lesions expanding per day would most likely not affect the overall amount of secondary inoculum produced and is mainly a function of the size of a given lesion. Lesion expansion is of more importance in polycystoma where lesions are submicroscopic and continue to expand until host tissue is completely destroyed or nearly so (14).

Sporulation per lesion, adjusted for lesion size, was significantly reduced on the partially resistant cultivars 'Bountiful' and 'Lemon' and on the completely resistant 'Katy' as compared to 'M26'. These data confirm previous reports of differences in sporulation per lesion on cultivars with varying levels of resistance to rhiniasis (14). The average number of oospores produced by a given lesion on 'M26' averaged across all rates of S_0 was $775 \text{ oospores cm}^{-2}$ of lesion area. The number of oospores produced per leaf for 'M26', calculated by multiplying $775 \text{ oospores cm}^{-2}$ of lesion area by the average proportion of leaf area with overlapping lesions (2.37%) and an average leaf area of 1588 cm^2 , is thus 29,600 oospores per leaf at the time of sampling in these tests. It is clear that the reduction of 18.95% in sporulation of lesions of M' given on 'Bountiful', 'Lemon', and 'Katy' have the potential to reduce the number of oospores released drastically during the infectious period of a given lesion. This in turn reduces the amount of inoculum available to propagate secondary cycles thus slowing epidemic development (14).

The effect of S_0 on oospores cm^{-2} of lesions was less clear. When the average number of oospores cm^{-2} of lesion is pooled across cultivars for 'M26', 'Bountiful',

'Lancet', and 'Katy' (possibly due to a lack of interaction between main effects in the study), a linear decline of 47% is observed as the rate of *St* increases from 0 to 10 T ha⁻¹. However, this response is significant only at $P=0.10$, and an examination of average by cultivar shows that, in reality, sporulation per lesion was dominated by those 'M201' only (Fig. 4-1c). Despite having nearly the same content of *St* in leaf tissue as 'M201', no change in sporulation can be identified in 'Roumere', 'Lancet', or 'Katy'. At 0, 5, and 10 T of salicic acid ha⁻¹, no wounds were recovered from lesions on 'Katy', and only a few were found at 3 T of salicic acid ha⁻¹. It is important to note that the total number of lesions available for measurement of number of wounds was smaller on the partially resistant and resistant cultivars, and the number decreased as the rate of *St* increased. For all cultivars except 'M201' small areas of samples contributed to better estimates of the number of wounds per² of lesions. In the case of 'Katy', sporulating lesions were absent up rates of *St*, making it difficult to measure sporulation. This problem could be remedied by increasing the number of plants inoculated, the number of replicates for each treatment, and the number of repetitions of the experiment. It appears that the rate of the pathogen experiment were not sufficient to estimate fully the effect of *St* on sporulation of lesions on partially resistant and resistant cultivars. Because the number of sporulating lesions found on the resistant cultivars was extremely small, sporulation per lesion is of minor importance when compared to the reduction in lesion number and would not be expected to be influenced by *St*.

Although an extended latent period has been identified as a significant component of resistance in several pathosystems (21,77,104,115,136), no significant differences in latent period of *M. grisea* were detected among cultivars in this study. These findings are

in agreement with those of Rouman (1977), who reported only small, insignificant differences in latent period among several tropical cultivars of rice with varying levels of resistance to *M. grisea*. He also reported that incubation period and latent period were nearly identical, as blast lesions were visible at sporulating within a few hours of appearance. In the present study, incubation period preceded latent period by 2–3 days, depending upon the cultivar. It is important to note that the tests conducted by Rouman (1977) were under tropical conditions in the greenhouse, and that only emerging susceptible-type lesions were evaluated in the estimation of incubation period. In contrast, both resistant- and susceptible-type lesions, which occurred together even on the blast-susceptible 'MD90', were considered valid for estimation of incubation period in this study. Resistant-type lesions were visible 1–3 days in advance of the appearance of susceptible-type lesions. Thus, coupled with water temperatures in the greenhouse used in this study could account for differences between those observed here and those of Rouman (1977).

Incubation period of *M. grisea* was significantly longer on the resistant cultivar 'Katy' than for 'MD90', 'Rasmanee', or 'Laminate', yet latent period did not differ among any of the cultivars. Polakowski (1984) states that incubation period and latent period tend to "vary in a parallel way". By this logic, the 4–5 day incubation period of *M. grisea* for 'Katy' should have translated into a latent period of 7–8 days instead of the reported 4–7 days. It is possible that the sample size used in estimate incubation and latent period for 'Katy' was too small to provide a reliable estimate. Resistant few lesions actually appeared on 'Katy', and even latent sporulation, the number of lesions evaluated was by necessity smaller than for the remaining cultivars. Evaluations were made on a 34-hour

leaves, and leaves that spawned only a few leaves following an evaluation would have been recorded as spawning a day later and would have inflated the latent period. The maximum period of *H. grisea* significantly lengthened as all substrates in the role of *B* applied was increased; however, there was no significant effect of *B* on latent period for any of the cultures. Sample size in the timing of evaluations may have biased the estimates. An increase in the number of inoculated plants, and thus number of leaves, and an increase in the number of evaluations within a 36-hour period could provide a more accurate estimate of maximum and latent period.

In field studies, presented in Chapter 3 and 4 of this dissertation, *B* was shown to reduce the rate of progress (λ) of epiphytic coffee blast and also to increase the level of resistance to leaf blight on partially resistant and susceptible cultivars of rice. From this study, it is clear that *B* acts in several fashions to spare production. The components of resistance most affected by *B* is the number of spawning leaves (relative infection efficiency) and how leaves extend, leaves die and sporulate per leaflet. By reducing relative infection efficiency, the number of spawning leaves that can maintain infection for secondary cycles is curtailed, and reduction in size of leaves further limit production of inoculum. This is best illustrated by considering Van der Plank's (1963) basic infection rate, R , and its influence on the production of inoculum. The basic infection rate is calculated as

$$R = N \times e$$

where N equals the number of spores and e equals the efficiency of those spores in establishing infections that produce spawning leaves. The overall effect on R is a

disrupts the production of infection. Reduced sporulation results in a depression of r , such as that observed in the field studies conducted in Chapters 3 and 4.

The results from controlled tests in the greenhouse on the effect of β on the severity of blight, measured as percent diseased leaf area, paralleled those from field studies with resistant, partially resistant, and susceptible cultivars. In the current study, disease was reduced on 'Lemon', 'Roanoke', and 'WDC6' by the application of β . No response was observed on 'King' to any rate of β . In the field, only partially resistant and susceptible cultivars showed reductions in severity of leaf blight when treated with β , as was observed in tests performed in the greenhouse. Because of the correlation in previously conducted field tests and the current study, the results obtained from this study are useful in the interpretation of the effects of β on severity of blight, and also components of resistance to blight in different genotypes in the field.

Some information about the mechanism(s) by which β acts to reduce blight can be drawn from the present study. The reduction in the number of sporulating lesions (relative infection efficiency) on partially resistant and susceptible cultivars when treated with isolates whose isolates lost the number of successful infections established per unit of inoculum was lowered. Inoculum resistance is therefore that it forms a physical or chemical barrier to penetration (92, 121, 140). It was observed that the total number of lesions, both resistant-type and susceptible-type, for a given cultivar did not change as the number of susceptible-type lesions was reduced, and instead decreased from 4.0 to 3.0 cm² to 0.0 cm² of leaf area as the rate of β increased from 0 to 10 T/ha.¹ It is possible that this effect of β may be due to the direct degradation of *M. phase*

actively secrete the apoplast, or even themselves, which is indicative of some form of blockage or signal by the pathogen.

Differences among cultivars and rates of β -glucanase length could also be influenced by the concentration of β -glucanase in apoplastic cells. Volk et al. (1989) hypothesized that lignin was could be oxidized by cupressin-like compounds in the walls of apoplastic cells, and Jennings et al. (78) later proved this. It does indeed form complexes with organic compounds in these cells. However, it is possible that decreased rate of fungus on β -treated plants is a result of heightened induced resistance mechanisms within the host. Solters has been shown to increase the amount of pathogen-related defense compounds, such as phenolics, peroxidases, and chitinases, in plants either from root warts challenged with fungal pathogens (24, 25, 40). In rice, the accumulation of phenolic compounds occurs in the margins of blast lesions following establishment of infection and independent upon the level of resistance in a given genotype of rice (12). Lesions on susceptible cultivars often lack a necrotic margin, while lesions on partially resistant and resistant cultivars are smaller and possess a pronounced margin (24, 123). Formation of a margin around lesions is a defense response to infection, and it is possible that β acts in some way to enhance this response. Biochemical and physiological studies on the infection process of *M. grisea* on rice are needed to determine the actual mechanism or mechanisms of β -mediated resistance to rice blast.

The results from this study underscore the importance of β in resistance to rice blast, particularly for partially resistant and susceptible cultivars. The cultivars used in this study came from breeding programs in the northeastern United States and were developed on loessial natural soils. Wheat 'Lansdown', 'Bismarck', and 'M96' were

gives us a *Scutellaria* seed without further expenditure with calcium when levels of disease were considerably higher than for the same cultivars treated with various levels of calcium nitrate. Growers who are developing cultivars for use in optimal soil ecosystems, or other Si-deficient areas, need to consider the impact of Si on components of resistance such as disease infection efficiency and lesion rate, and the effect this might have when cultivars adapted for Si rich environments are moved into Si deficient soils. Also, judging from the rate response to calcium nitrate observed on the cultivars tested in this study, improved uptake of Si could benefit cultivars grown in areas not deficient in Si. Considering the increased uptake of Si might be explained by which nutrient ratio varies with various levels of resistance to blast could be made more resistant by the disease.

CHAPTER VI SUMMARY AND CONCLUSIONS

Over a three-year period, *Se- alone* or with fungicide applied at specific times and at reduced rates, was shown generally to reduce severity of leaf and neck blight. *Se- alone* significantly reduced leaf blight severity at Santa Rosa and Matamoros, and a single fungicide application provided further reductions. The incidence of neck blight was reduced by *Se- alone* significantly at Matamoros only, however, the addition of fungicide provided significant levels of control at both locations. Under conditions of high disease severity, such as were present at Santa Rosa, three or more fungicide applications plus *Se-* were needed to provide maximum reductions of neck blight. At Matamoros, a rate with low disease severity, applications of fungicide at heading, 15% and 30% heading plus *Se-* controlled neck blight as well as two to five sprays plus *Se-*. At Matamoros, *Se- alone* significantly reduced yield, and the greatest reductions were observed with *Se-* plus two to three fungicide sprays. Returns alone did not increase profits at Santa Rosa, and the use of fungicides was necessary to reduce disease significantly. Returns plus one to five fungicide sprays significantly improved yield, with two or more applications showing the greatest improvement. At Matamoros, *Se- alone* significantly raised profits and all *Se-* plus fungicide treatments provided larger profit when compared to untreated controls. At both sites, *Se-* plus fungicides reduced grain discoloration. Two or more fungicide sprays plus *Se-* reduced discoloration to the greatest degree. At Matamoros, *Se- alone* significantly reduced discoloration. Fertilization with *Se-* appears to be a promising means by which

the number of fungicide applications can be reduced during a growing season. Because of the low rate (400 g/ha) of Zn applied, disease control was less under conditions of high severity of blast than under conditions of low severity of disease. Higher levels of severity of disease will require the application of greater concentrations of Zn to soil.

When applied at 1000 g/ha, Zn controlled blast and neck blast as effectively, and in some cases more effectively, as commercially available fungicides. More importantly, yields were increased by Zn to the same degree or greater than the fungicide subphthalic and triphthalic at labeled rates. Therefore, it is possible that the use of fungicides could be discontinued altogether if adequate levels of Zn are maintained in soil. Because applications of Zn made in 1993 had significant residual activity in 1996, amendment of soil with calcium sulfate as a fertility treat appears to be unnecessary to provide acceptable control of disease and increased yield. More work is necessary to determine the actual longevity of activity in soil for a given application of Zn , and also to determine how often Zn should be applied and how much Zn is required to sustain adequate levels of plant-available Zn in soil.

In terms of disease progress, Zn reduced the overall severity of blast blast by reducing the apparent infection rate (r) of the epidemic. The reduction of r in turn resulted in lower amounts of final disease and lower AUDPC's. The effect of Zn on r suggests an effect on one or more of the components of resistance in rice to blast (114,120).

Experiments were run to evaluate yields and disease control as partially resistant and non-equilibrium cultivars. When the level of disease was low, Zn raised resistance to blast to acceptable and partially resistant values of rice to the same levels occurring in

a resistant cultivar (BRAT 143). In all cultivars, yields were significantly increased by the addition of Zn, and leaf weight was decreased.

In terms of the effects of Zn on components of resistance to rust that is susceptible, partially resistant, and resistant cultivars, it was shown that the number of sporulating lesions arising from a given amount of inoculum (relative infection efficiency) was significantly reduced by the addition of micron zinc at 3, 5, and 10 T ha⁻¹. The size of lesions of blast and sporulation of individual lesions were reduced to a similar degree by applications of micron zinc. The effects on these components of resistance indicate that Zn forms a physical barrier to penetration by the blast fungus, and possibly interacts with host defence mechanisms. Further work, both histological and physiological, is needed to determine effects on mechanisms of resistance to blast in rice. The rice yield was found, regardless of the level of resistance possessed by each, accounted for to the same degree. Because of the differential responses to micron zinc treated with micron zinc for each cultivar, it is possible that utilization of Zn varies for different cultivars.

To minimize Zn as an effective resource which blast, and leaf weight can be controlled, and by which yields and grain quality can be improved. These findings are important in that they provide additional tools for management of important and destructive rice diseases, and also a means by which yields of rice may be increased without further genetic improvements.

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BIOGRAPHICAL SKETCH

Kenneth Wesley Sorkold Jr., son of Kenneth Wesley Sorkold Sr. and Irma Jean Dean, was born in Louisville, Kentucky, on November 5, 1944. Kenneth attended Jeffersonville High School, graduating in 1962, before enrolling at the University of Louisville. In 1968, he transferred to Auburn University and received a degree in integrated pest management in 1969. After a two-year internship with Rhone-Poulenc AG in North Carolina, Kenneth returned to Auburn and began work for a master's degree in the Department of Plant Pathology. He focused his thesis on the control of seedborne diseases of peanut with adjuvants and fungicide placement in 1974, and accepted an appointment at the University of Florida to conduct doctoral research on the effects of adjuvants for control of root rot. While at the University of Florida, Kenneth spent over a year at the Centro Internacional de Agricultura Tropical, located in Cali, Colombia, where he conducted field work for his dissertation research. On April 4th, 1976, Kenneth married Patricia Martinez, of Bogota, Colombia. He will graduate with a Ph.D. Degree in Plant Pathology in August 1976, and has accepted a position with Unipet Chemical Company as a plant pathologist in the research and development department.

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